The environmentally optimal trading ratio[*]

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Paper presented at the Annual Meeting of the

American Agricultural Economics Association, August 5-8, 2001 Chicago, Illinois

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[*] The helpful comments of Paul Mitchell and valuable editorial assistance of Michele Zinn are gratefully acknowledged.

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Abstract: In the standard economic model of cap and trade policies, the regulator is assumed to place zero value on pollution reductions below the cap. This paper considers an alternative case, where the policy makers can manipulate the rules of the program to achieve improved environmental performance. This is achieved by manipulating the trading ratio, the units of pollution credits that are obtained for each unit of pollution reduction. Using a parsimonious model of a transferable discharge permits program, we identify the *environmentally optimal trading ratio* that maximizes the environmental gains of trading. The model suggests an alternative explanation why non-unitary trading ratios are common and is a counterpoint to the cost-minimizing model that predominates in economics. We conclude by recommending that a middle-ground should be sought, where both environmental gains and cost efficiencies are given weight.

Keywords: Transferable discharge permits, pollution, market-based policies

I. Introduction

The standard economic model for the analysis of transferable discharge permits is one in which the regulator’s objective is to minimize the cost of achieving an environmental goal or goals (e.g., Montgomery 1972, Baumol and Oates 1988). While this model provides many important insights and has normative appeal, it is has some important limitations as a descriptive portrayal of the environmental policy process. One critical limitation of this model is that as long as the pollution standard is met, it is implicitly assumed that zero value is placed on additional pollution reductions. This specification is not only counterintuitive; it is inconsistent with legislation and commentary by regulators and stakeholders.

In this paper we model a transferable discharge permits (TDP) program in which the policy maker seeks to maximize environmental quality subject to a constraint on the cost. In principle, this “primal” specification could lead to the equivalent outcome as the “dual” problem typically considered. However, when policy is developed incrementally -- when the trading program is established *after* the initial allocation of abatement responsibilities -- then the rules of the trading program will differ from those that would be set in a cost-minimization model. In particular, policy makers will tend to discount credits generated to create excess pollution abatement, intentionally introducing inefficiencies that would be avoided in the cost minimizing model.

Table 1
Examples of trading ratios in water pollution trading programs

PROGRAMS	TRADING RATIOS
Kalamazoo River Project, Michigan	1:2
Dillon Reservoir, Colorado	1:2
Tar-Pamlico, North Carolina	1:3⁺ 1:2*
Rahr Malting, Minnesota	1:1⁺⁺
Fox River, Wisconsin	1:1
Long Island Sound, New York; and Connecticut	36 area-specific ratios varying from 1:1 to 1:9

+: Trading ratio for cropland BMP;
*: Trading ratio for confined animal operation
++: Ratio of the maximum monthly average $CBOD_5$ that can be discharged relative to the required units of nonpoint load reduction (Minnesota Pollution Control Agency, 1997)
Source: Fossett et al. 1999.

Our model provides an alternative explanation for the widespread use of trading ratios in TDP programs. A number of papers have analyzed this issue in recent years. Malik, Letson, and Crutchfield (1993) find the cost-minimizing trading ratio given uncertainty and differential enforcement costs. Shortle (1987) considers the case of a policy that seeks to maintain a particular level of expected damages (as opposed to loads). Horan (2000) considers the choice of trading ratios when political as well as economic forces are at play. Other papers, including Hoag and Hughes-Popp (1997) and Randall and Taylor (2000), have emphasized that trading ratios can have a deleterious impact on a TDP program's success. The attention to trading ratios is important given their widespread use in TDP programs. While one-to-one trades are allowed in some programs, including the national SO_2 trading program, other programs have incorporated trading ratios that discount the value of the generated credits. Texas' Emission Reduction Credit Banking and Trading Program grants one credit for each 1.10 to 1.15 unit of NO_x that are reduced. As seen in Table 1, in programs involving water pollution, trading ratios far away from 1:1 are common.[1]

Of course the most obvious purpose of a trading ratio is to equate the damages caused by different polluters so that an increase in pollution at one point source is at least offset by the decrease in pollution elsewhere. When a unit of pollution from two sources lead to different loads at the receptor of interest, then the environmental impact must be equated through the trading ratio. We will use the term *trading ratio*, *T*, to refer to the number of units of pollution *loading* that can be added by one source for each unit that is reduced at another source. A trading ratio of 1, therefore, would imply that pollution will remain unchanged as a result of any trade. If *T* is less than one, then a one unit reduction in pollution load generates less than a complete right to increase pollution at another source.[2]

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[1] It is often argued that low trading ratios are justified in water pollution TDP programs because of the inherent riskiness associated with some of the traders, particularly when trading involves non-point source polluters. Horan (2000) points out that this argument is inconsistent with the economic theory on the issue (Malik, Letson, and Crutchfield 1993).

[2] Note that we define *T* as the inverse of the trading ratio as it is usually presented (e.g., Hoag and Hughes-Popp). As will be clear below, this specification has the advantage that the relevant ratio is bound between zero and one, facilitating graphical presentation.

Trading ratios less than one create inefficiencies by creating a “wedge” between the marginal abatement costs of buyers and sellers. For these reasons, the manipulation of trading ratios to achieve environmental goals has been criticized as “undermining the raison d’être for permit trading” (Randall and Taylor 2000, 229). From the perspective of a policy maker, however, a trading ratio less than one might be viewed favorably since then each trade actually causes a net decrease in pollution. Hence, if the trading ratio is an instrument through which policy makers seek to reduce pollution, then levels less than one will be sought. In this paper we identify the trading ratio that maximizes the additional pollution reduction achieved through the program, which we will refer to as the *environmentally optimal ratio*.

The paper is organized as follows. The next section provides evidence that policy makers frequently do not follow a cost-minimizing approach to environmental policy. Rather, we find that costs are frequently treated as a constraint on the policy’s objective of maximizing environmental quality. In section III, we formalize this perspective in the context of a simple model of a TDP program and derive the environmentally optimal trading ratio in terms of the elasticities of supply and demand for credits. The theoretical results indicate that in many situations trading ratios below 1:2 may be environmentally optimal, a result which is consistent with many observed trading ratios. The final section of the paper concludes with a discussion of the implications and interpretations of our results.

II. The case for an alternative model of the policy-maker’s objective

The standard economic model of the environmental policy process (e.g. Baumol and Oates) can be characterized as follows. Through a scientific and political process, an environmental standard is chosen. While this standard may attempt to weigh the policy's marginal benefits and marginal costs, typically such detailed economic analysis has not been carried out and the chosen standard does not necessarily attempt to achieve a social optimum. Once the standard is chosen, it is presumed that there is a separate stage during which the policies to achieve the standard are chosen. Command and control regulations, taxes, subsidies, and TDPs are the policy instruments that are normally considered.

An alternative characterization of the policy process is one in which regulations are established to achieve environmental improvements up to the point at which the cost of further restrictions is politically untenable. Once this initial political constraint is reached, the policy maker continues to seek the highest possible level of environment quality while keeping costs below the politically unacceptable threshold.

This alternative framework seems consistent with many environmental policies. Consider, for example, the technological restrictions that are typically referred to as "command and control" regulations. While economists usually portray such regulations as hard-and-fast rules, in practice there are often important qualifiers placed on the definitions of the required "Best Management Practices." For example, in the regulations governing pollution from pulp and paper manufacturers, firms are required to use the "best available technology *economically achievable*," and elsewhere, the "best *practicable* control technology" (U.S. Code of Federal Regulations, 40CFR430, emphasis added). While the language used in such restrictions varies, the underlying implication is that cost or "practicality" affect the standard that is required; if costs change so would the required technologies.

Similarly, in TDP programs a survey of existing programs shows that it is often the case that there is no fixed pollution abatement target. Instead, policy makers seek to use the programs to achieve environmental gains through the trading itself. For example, the Texas Emission Reduction Credit Banking and Trading Program is promoted as providing "additional flexibility for complying with the Texas Clean Air Act while *creating a net reduction in total air emissions with each transaction*" (TNRCC 2000, emphasis added). Similar rhetoric is found in discussion of the use of TDPs to control water pollution. The National Wildlife Federation states, "Trading should only be considered if the overall pollutant load is reduced in the watershed" (National Wildlife Federation 1999, p. 19). This perspective is reflected in regulations such as the State of Michigan's proposed rules for water quality trading in which the overseeing agency is required to establish "[t]rading ratios … to address uncertainty and *provide a net water quality benefit* (State of Michigan Department of Environmental Quality 1999, Rule 9.4, emphasis added).

We find, therefore, compelling evidence that the traditional economic model of pollution control is inconsistent with the way much policy is actually implemented. There is value placed on pollution reductions even after the initial pollution cap has been set. The alternative model, which we develop in the next section, takes the position at the opposite end of the spectrum, where TDP rules are set to maximize the environmental benefits created by trading.

III. The model and results

We formalize our representation of the regulator's pollution minimization problem in the context of the most simplified pollution control problem: the case of a nonstochastic and uniformly dispersed pollutant from a large group of perfectly observable and fully compliant polluters. We assume that through political haggling and scientific study an initial cap on allowable pollution has been set and pollution rights have been allocated. Although we do not formally model the process through which the initial cap is established, it can be thought of as the point at which the cost of tightening the requirement would be politically unacceptable. After the standard is set, a more flexible TDP approach is then proposed to take advantage of differential abatement costs. In developing the rules of the TDP program, the policy maker seeks to adjust the trading ratio in order to maximize the environmental benefits of trading.

Under the simplifying assumptions that we have made, if cost minimization were the policy maker's objective, then the economically optimal trading ratio would clearly be one (Malik, Letson, and Crutchfield 1993). However, when value is placed on additional environmental benefits, then it would be desirable to use a nonunitary trading ratio so that each transaction actually reduces total pollution. On the other hand, if the ratio is too low it will choke off trading and eliminate any environmental gains. The environmentally optimal trading ratio must strike a balance these two forces.

Because of the trading ratio, it is helpful to define two distinct units for pollution. Abatement credits, a, are generated by firms that reduce their loads in order to make sales in the market. Emission credits, e, must be obtained by firms seeking to increase their loads beyond the initial endowment. For each unit of a generated, only T units of e are created. The original standard will be met as long as $T \leq 1$. For $T<1$, two prices will exist in the market: p_a, which will be perceived by those who supply credits; and p_e, which will be perceived by those who demand credits. Since we assume that there are no brokerage or transaction costs, these prices must be proportional, i.e.,

$$p_a = Tp_e. \tag{1}$$

In equilibrium, the regulations require that

$$D\left(p_e^*\right) = TS\left(p_a^*\right) = TS\left(Tp_e^*\right) \tag{2}$$

where $D(p_e)$ is the demand for e and $S(p_a)$ is the supply of a and p_e^* and p_a^* are the equilibrium prices of e and a respectively. If T is less than one, then each unit of e purchased will result in a reduction in net reduction pollution loads of (1-T) units. In equilibrium, the total reduction in pollution, $R(T)$, is determined by the equation

$$R(T) = (1-T)\,S\left(Tp_e^*\right). \tag{3}$$

Figure 1 presents the equilibrium prices, and the supply and demand of credits for various levels of T for a simple TDP program in which both the willingness to pay (WTP) of those who demand credits and the willingness to accept (WTA) of those who supply credits are linear functions of the prices they face. As seen in the figure, low values of T create a large gap between p_e and p_a. The effect of this gap is to substantially reduce trading, so that the number of credits demanded increases in T. The gap between the supply of abatement credits and the demand for emission credits indicates the pollution reduction that is achieved in equilibrium, which in this case presented reaches a maximum at about T=0.4.

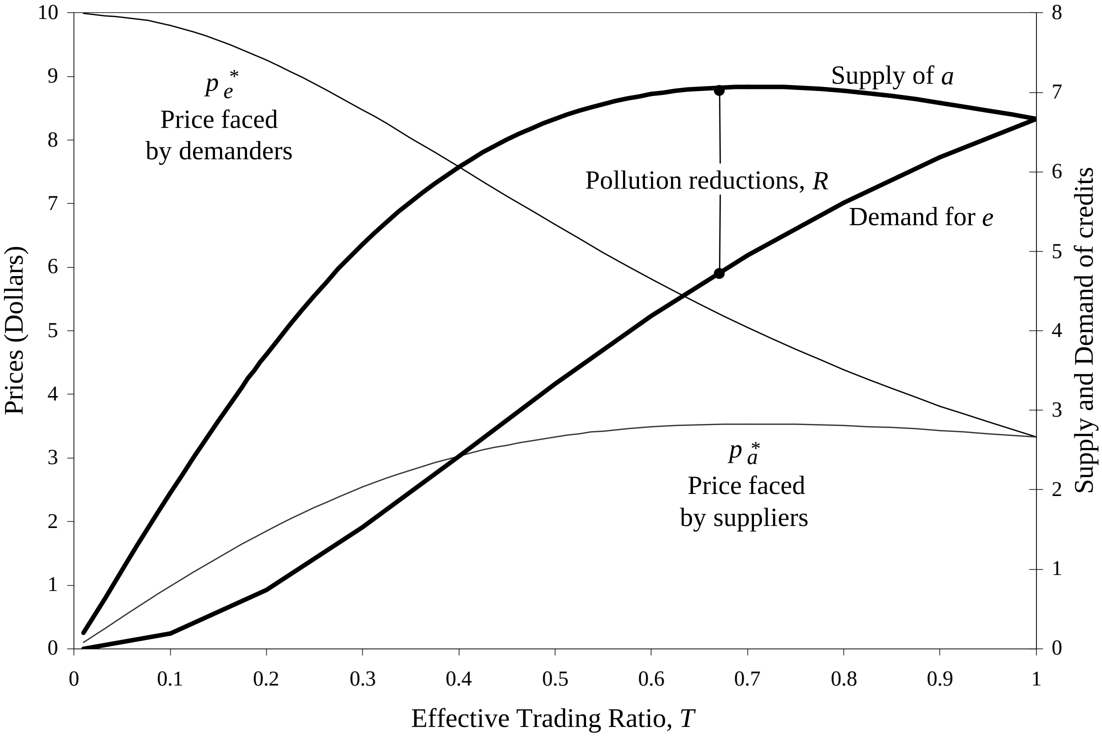

Figure 1
Equilibrium prices and pollution reduction given linear supply and demand functions
(*WTP*=10-1·*e* and *WTA*=0+0.5·*a*)

The environmentally optimal trading ratio is found by maximizing (3) with respect to T. The first-order condition for an interior solution of this problem leads to

$$\left(1-T^*\right)\frac{\partial S^*}{\partial p_a}\left(p_e^* + T^*\frac{\partial p_e^*}{\partial T}\right) = S^* \tag{4}$$

where S^* is the equilibrium supply of a. The right-hand side of this equation is the direct affect on pollution abatement of changes in T. The left-hand side is the indirect affect, i.e., the change in the quantity of credits supplied because of the shift in the credit supply function.

Using (1), it follows that $\frac{\partial p_a}{\partial T} = p_e + T\frac{\partial p_e}{\partial T}$, or $\frac{\partial p_e}{\partial T} = \frac{1}{T}\left(\frac{\partial p_a}{\partial T} - \frac{p_a}{T}\right)$. Substituting for p_e^* and $\partial p_e^* / \partial T$ in (4) and simplifying we obtain

$$T^* = 1 - S^*\left(\frac{\partial S^*}{\partial p_a}\frac{\partial p_a^*}{\partial T}\right)^{-1}. \tag{5}$$

This expression can be rewritten in terms of elasticities:

$$T^* = 1 - S^*\left[\frac{S^*}{T}\left(\frac{p_a^*}{S^*}\frac{\partial S^*}{\partial p_a}\frac{T}{p_a^*}\frac{\partial p_a^*}{\partial T}\right)\right]^{-1} = 1 - T^*\left(e_{Sp}\cdot e_{pT}\right)^{-1},$$

where e_{Sp} is the price elasticity of supply and e_{pT} is the elasticity of the equilibrium price of *a* with respect to changes in *T*. Solving for T^* yields the optimal trading ratio:

$$T^* = \frac{e_{Sp}e_{pT}}{e_{Sp}e_{pT}+1}. \tag{6}$$

The equilibrium supply price, p_a^*, is a function of *T* determined implicitly by the relationship $TS\left(p_a^*(T)\right) \equiv D\left(p_a^*(T)\cdot T^{-1}\right)$. Taking the derivative of both sides of this identity with respect to *T*, we obtain

$$S^* + T\frac{\partial S^*}{\partial p_a}\frac{\partial p_a^*}{\partial T} = \frac{\partial D^*}{\partial p_e}\left(\frac{\partial p_a^*}{\partial T}\frac{1}{T} - \frac{p_a^*}{T^2}\right), \tag{7}$$

where D^* is the equilibrium demand in terms of *e*. Multiplying both sides by p_e/S^* and using (1) and (2), we can rewrite (7), $\frac{p_a}{T} + \frac{\partial S}{\partial p_a}\frac{p_a}{S}\frac{\partial p_a}{\partial T} = \frac{\partial D}{\partial pe}\frac{p_e}{D}\left(\frac{\partial p_a^*}{\partial T} - \frac{p_a}{T}\right)$, which can be simplified to $e_{pT} = \frac{\left(1+e_{Dp}\right)}{\left(e_{Dp}-e_{Sp}\right)}$ where the price elasticity of demand, e_{Dp}, is less than zero. Substituting this expression into (6) leads us to the optimal trading ratio,

$$T^* = \frac{e_{Sp} + e_{Sp}e_{Dp}}{e_{Dp} + e_{Sp}e_{Dp}} . \qquad (8)$$

Although the model that led to (8) is quite simplistic, it is also quite general since it is independent of the functional forms of the industry’s marginal abatement costs. The result is remarkably parsimonious. To choose the environmentally optimal ratio the policy maker need only estimate the elasticities of demand and supply for these credits. These could be derived from models of the industry’s abatement technology, although McKitrick (1999) has recently pointed out the potential for nondifferentiability of the marginal abatement cost curve, which would complicate matters.

Figure 2 presents the surface of the function (8) for elasticities less that ten in absolute value. There are a number of interesting characteristics of this surface. First, very low trading ratios predominate for all but highly elastic demand and supply functions. Even with both elasticities at 3 in absolute value, the optimal trading ratio is only 0.5. Hence, most of the trading ratios presented in Table 1, which fall between 1:2 to 1:3, could be environmentally optimal for plausible elasticity values.

If the demand is inelastic over the entire domain, $e_{Dp} \leq 1$, then there is no interior solution as T^* goes to zero. This occurs because although a reduction in T decreases the number of units of e demanded, demand does not fall as fast as the proportion of the supply that goes to environmental improvements increases. If prospective purchasers of credits have very steep marginal abatement cost curves, then the agency can exploit this characteristic by imposing very low trading ratios and generating substantial pollution reductions through the limited trading that results.

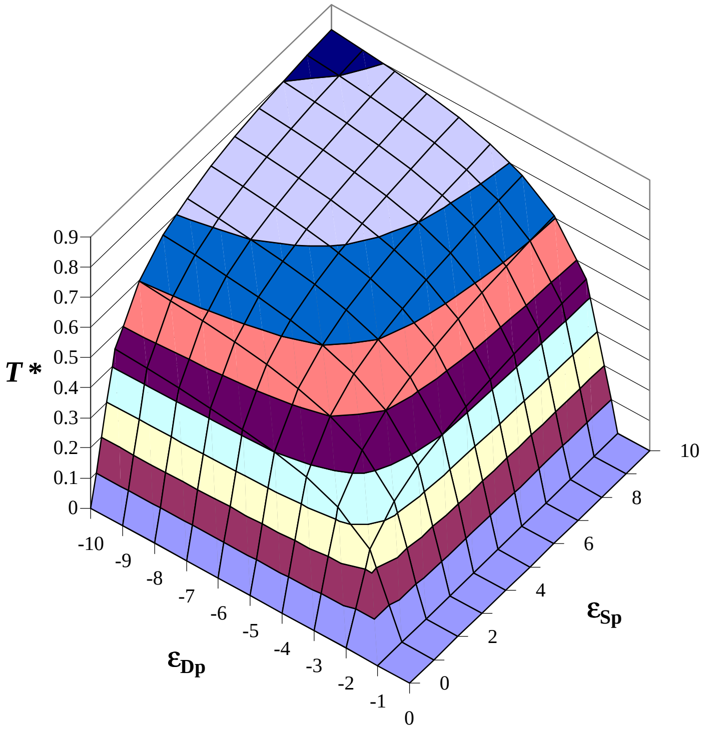

Figure 2
Optimal trading ratio
as a function of e_{Sp} and e_{Dp}

Another interesting feature of the surface in Figure 2 is its sharp, Leontief-like, curvature. Although T^* is monotonically increasing in the absolute values of the elasticities, increases in one of the elasticities while holding the other constant leads to only small changes in the optimal value of *T*. Hence, *T* might be chosen quite accurately with knowledge of only the smaller of the two elasticities.

IV. Discussion

The model of pollution trading that we have proposed here is fundamentally different than that which is typically presented in the economics literature. We emphasize that we do not wish to promote this model as normatively preferred to the standard cost minimization model -- choosing the trading ratio to maximize environmental gains leads to outcomes that could be achieved at lower cost with a stricter environmental standard and a trading ratio of 1. However, we do feel that the model is useful both as descriptive of the way environmental policy is actually implemented and as a counterpoint to the standard model.

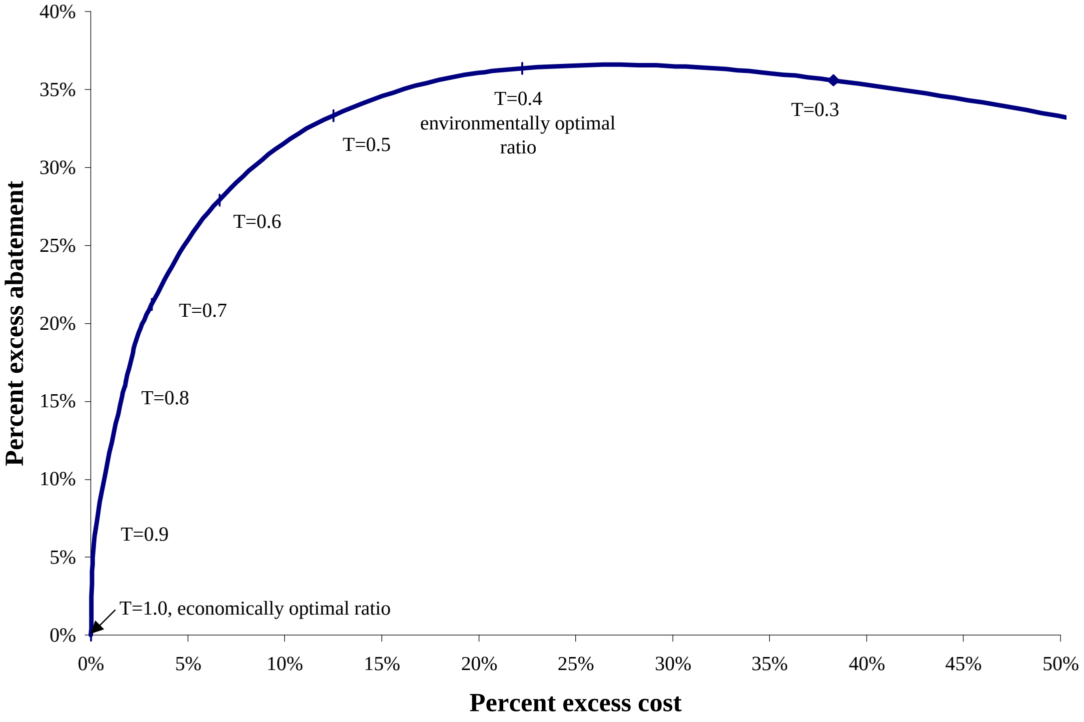

Figure 3
Trade-off between environmental gains (excess abatement) and cost efficiency in a TDP market with linear supply and demand functions (see Figure 1)

The gap that is created by trading ratios less than one introduces inefficiencies since the same level of total abatement could be achieved at lower cost with a stricter initial endowment and *T*=1. The extent of the efficiency losses is particular to the industry. For example, in the case of linear demand and supply presented in Figure 1, the use of the environmentally optimal trading ratio of *T*=0.4 increases abatement by 36% over the initial standard, but the cost of achieving this goal is 22% higher than the cost efficient allocation. However, there is a trade-off between environmental improvements and cost efficiency. In Figure 3 we present the efficiency costs and environmental gains associated with a variety of trading ratios in the context of the linear model considered above. While the environmentally optimal trading ratio is quite costly, less distortionary values of *T* can still deliver substantial pollution reductions at much lower cost. A trading ratio of *T*=0.8, for example, leads to a 16.3% increase in the pollution abatement at a cost that is only 1.8% greater than the cost minimizing allocation.

Because of the model's parsimonious structure, it has many limitations. The lack of uncertainty, transaction costs, and enforcement costs are particularly important omissions. It would be useful to expolore extensions of the model that build on Malik, Letson and Crutchfield (1993) to address uncertainty and enforcement costs or on Stavins (1995) to address transactions costs. However, a more important and more substantial extension would be to develop a unified framework in which both economic efficiency and environmental gains are given some weight.

The standard economic model is limited in that marginal improvements in environmental quality are given no weight. Our model places no weight on cost savings so that the environmentally optimal trading ratio ignores the inefficiencies it creates. These two models lie at the extremes of a policy frontier along which both environmental improvements and cost-efficiency might be valued. In reality, we expect that environmental policy lies somewhere on the interior of this spectrum, where abatement-cost reductions and environmental improvements both enter into the policy maker's calculus. In clearly identifying the other end of the spectrum, we seek to draw attention to the need to step towards the middle.

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50 word abstract:

This paper considers the *environmentally optimal trading ratio*, that ratio that maximizes the excess pollution reductions achieved through a transferable discharge permit (TDP) program. For a simple but quite general specification, this ratio can be expressed as an expression of the elasticities of supply and demand for credits. The issue of

when the program seeks to reduce pollution below the established cap.

Trading ratios in transferable discharge permit (TDPs) programs, are often used to cause environmental improvements beyond the cap that establishes the program.

this is often done via the trading ratio, the units of pollution credits that are obtained for each unit of pollution reduction. Using a parsimonious model of a TDP program, we identify the *environmentally optimal trading ratio* that maximizes the environmental gains of trading. Our results provide an alternative explanation why non-unitary trading ratios are common and is a counterpoint to the cost-minimizing model that predominates in economics. We conclude by recommending that a middle-ground should be sought, where both environmental gains and cost efficiencies are given weight.