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SPATIAL VARIATION IN BENEFITS AND COSTS, OR WHY POLLUTION ISN'T ALWAYS FOR SALE

by

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Spatial Variation in Benefits and Costs, or Why Pollution Isn't Always for Sale

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Spatial Variation in Benefits and Costs, or Why Pollution Isn't Always for Sale

Marketable permits are proving to be a very effective way of reducing the costs of achieving a specified emissions target for air pollution. From the initial cautious application of these principles in such programs as the Bubble and Offset (Cropper and Oates), an increasing number of programs have used permits to allow pollution reductions to be made at lower cost. The sulfur dioxide trading program under the 1990 Clean Air Act Amendments in the U.S., probably the most ambitious application, is estimated to have reduced the costs of achieving the specified emissions target by $225-$375 million (Schmalensee et al.).

At the same time, concerns are often raised that marketable permit programs might lead to inequitable distribution of emissions. The effects of many pollutants are local or regional.[1] If trading of pollution emissions on a one-to-one basis is permitted across large distances, emissions in the region with low marginal costs of abatement will decrease, and emissions in the region with high marginal abatement costs will increase. This approach may lead to the creation of hot spots – places where pollution is higher than in other places – because one-to-one trading does not reflect differences in marginal damages across regions. (The sulfur dioxide trading program limits this effect by requiring that trades not lead to exceedance of the national ambient air quality standard for sulfur dioxide in any place.) Thus, efficiency can decrease through wide-area trading. Additionally, equity concerns are often raised. In some cases, the resulting disproportionate exposure of minority populations or poor people to air pollutants has become an environmental justice issue.

Alternatives to one-to-one trading include zoned systems (where trades are permitted only within specified zones), restricting trades to those that do not lead to violation of an air quality standard at any point, and trades weighted by the damages they cause at specified pollution monitors (Cropper and Oates). The third of these approaches could involve substantial modeling and measurement costs to keep track of the effects of each source on the monitoring stations. The first two are clearly intended to avoid hot spots in a less costly fashion, though there may be benefits foregone from more liberal trading rules. In all cases, the value of a permit as a pure property right is more limited.

Thus, if one-to-one trading is the policy being proposed, the scope of the trading involves tradeoffs. On the one hand, having trades over long distances increases the likelihood that marginal abatement costs will vary, and thus is likely to lead to greater reduction in abatement costs, than more localized trading schemes. On the other hand, having trades over long distances might well aggravate damages in some locations, since the variation in total benefits will be greater over long distances.

This paper will explore the tradeoff between local and long-distance trading using the framework developed by Weitzman and Adar and Griffin (and further explored by Stavins) for uncertainty and the extension of that framework to heterogeneity developed by Mendelsohn. Marginal benefits and marginal costs are assumed to vary with each pollution source. Trading can either be limited to a subset of polluters within a region, or it can be extended to the whole region. The analytical results show that, if the initial allocation of permits within a region is that which maximizes localized net benefits, widening the trading region will always reduce efficiency, since the more localized

[1] The most notable exception is likely to be greenhouse gases such as carbon dioxide. For these gases, damages are associated with total emissions and do not vary with the location of the source.

permit scheme is already at an optimum. If, however, the initial allocation of permits is not that which maximizes localized net benefits, then widening the trading region can lead to either net benefits or net costs.

This theory is then applied to the case of ozone regulation in California's San Joaquin Valley. This valley, an extremely productive agricultural region, has very high levels of ozone, a pollutant that both causes physical discomfort to people and inhibits crop production. Previous work on ozone in this region (Kim; Kim, Helfand, and Howitt) shows that both the marginal benefits and the marginal costs of ozone regulation vary across the valley. In the aggregate, the benefits of abatement exceed the costs for 1990 levels of ozone, but the net benefits are distributed inequitably across the Valley. These simulations will examine what scale of trading (only within counties, across some counties, or across the entire Valley) leads to the greatest net benefits.

Spatial Heterogeneity and Marketable Permits

This paper draws on two (mostly separate) strands of the environmental economics literature. The first is the literature on spatial effects in marketable permits; the second is the literature on the effects of uncertainty in the choice of regulatory instrument. Mendelsohn's paper uses the techniques of the latter to investigate the issues of the former; this paper will follow in that path.

Spatial Effects and Marketable Permits. The literature on emissions trading has considered location issues ever since the seminal article by Montgomery. This literature shows the possibility of markets for ambient air quality, where firms buy and sell permits based on the damages caused at a number of receptors. Each permit bought or sold by a firm, for each receptor, has to be weighted by a transfer coefficient representing the damage caused by each unit of a firm's emissions at that receptor. Though a regulator only needs to specify total damage permitted at any receptor, a polluter must collect permits reflecting its damages at every receptor that it affects. As Krupnick et al. point out, this system is obviously highly cumbersome for the polluter (and could potentially be difficult for a regulator to enforce).

Tietenberg discusses several alternatives to the ambient permit system: emission permits, zonal permit systems, and trading ratios. Under the first, emissions are traded on a one-to-one basis, typically with a constraint that air quality goals be achieved at all receptors. If air quality goals are truly to be achieved in this scheme, sources influencing the most sensitive receptors will have to face strong restrictions on their emissions. If these sources have high abatement costs, and therefore are likely to purchase permits, the number of permits allocated to the region may have to be very low to induce cleanup by these sources. It is thus possible for abatement costs under this scheme to be higher than those under a command-and-control scheme requiring these sources to reduce their emissions. Zonal trading reduces this problem by allowing trades only when firms are in the same zone. If zones are designed so that firms have similar effects on key receptors, one-to-one trading may approximate the efficient solution. A key difficulty with this system is determining the initial allocation of permits to each region. Imposing restrictions on trades, or requiring that trading be done using a ratio higher than one-to-one, may be useful additions to an emissions permit system in some cases, as long as these restrictions are designed with the environmental goals in mind.

These papers typically take pollution levels at a receptor as a constraint on the cost-minimization problem, rather than examine the total net benefits of pollution. This paper will examine the net benefits of different methods of allocating permits to zones. Under different scenarios, the planner is assumed to have different levels of information about benefits and costs within zones. How the planner allocates permits initially has a significant effect on the efficiency of zonal trading.

Prices, Quantities, Uncertainty, and Heterogeneity. Weitzman and Adar and Griffin analyzed the effects of uncertainty in marginal benefits and marginal costs to the choice of regulatory instrument. These analyses found that uncertainty in marginal benefits did not affect the choice of regulatory instrument, but uncertainty in marginal costs can lead to either a price or a quantity instrument being more desirable, based on the relative slopes of the marginal benefit and marginal cost curves. Stavins' analysis emphasized the importance of correlation of marginal benefits and marginal costs. If this correlation exists (and he argues that it is likely), then the difference in the effects of price and quantity instruments is affected by the uncertainty in marginal benefits as well as by the correlation.

Mendelsohn redefined Weitzman's analysis to consider heterogeneity of damages and costs instead of uncertainty over them. In his case, variation in marginal damages does not directly influence the choice over a price instrument or a quantity instrument, but variation in marginal costs as well as the covariance of marginal benefits and marginal costs affect the choice.

These analyses, with the exception of Mendelsohn, focus on the issue of the absolute choice between a quantity instrument and a price instrument (the latter of which includes marketable permits) rather than an intermediate case, the degree of variation to be permitted. (Mendelsohn discusses, but does not specifically analyze, the issue of multiple trading regions. His empirical analysis of sulfur dioxide emissions in the New York area does consider multiple trading regions.) In all these cases as well, the regulatory instruments for each scenario are chosen optimally by the regulator. That is, some version of expected marginal benefits are set equal to expected marginal costs for all these variations. The following analysis first extends this discussion to look at the effects of several different (suboptimal) initial allocations of permits. In addition, it specifically examines when more localized trading is desirable vs. when larger trading regions increase societal gains.

The Model

The following analysis uses Weitzman's quadratic approximation with Mendelsohn's approach and notation, which can be translated fairly directly into the notation of Weitzman, Stavins, or Adar and Griffin. Total benefits and costs of pollution abatement by firm *i* are assumed to be quadratic functions of the level of abatement, Q_i. Each firm *i* has a shift variable associated with its marginal benefits and marginal costs, representing its specific impacts and costs. The benefits of abatement thus are:

$$B_i = A_0 + (A_1+X_i)Q_i - A_2Q_i^2,$$

with A_1, $A_2 \geq 0$, and X_i a shift variable representing the benefits associated with abatement from that particular firm. E(X) = 0 when the expectation is taken over all firms. Similarly, the costs to firm *i* of abating are assumed to be:

$$C_i = C_0 + (C_1+Z_i)Q_i + C_2Q_i^2,$$

with Z_i representing an individual firm's shift variable for abatement costs, $E(Z_i) = 0$ over all firms, and C_1, $C_2 \geq 0$. Net benefits from firm *i* are therefore

$$NB_i = (A_0-C_0) + (A_1+X_i-C_1-Z_i)Q_i - (A_2+C_2)Q_i^2.$$

At this point, four scenarios will be presented. The first, the social optimum, represents the case where each firm's marginal benefits are set equal to its marginal costs. The subsequent scenarios all involve comparisons between trading across an entire region and trading only within limited sub-regions. The second scenario compares the case where, in each sub-region, expected marginal benefits are set equal to expected marginal costs, to the case where trading (with the same number of total permits) is allowed throughout the region. In the third case, the planner does not know individual circumstances in any sub-region; permits are given to every firm based on the assumption that the expected values for X and Z are zero for all regions. The final case considers the situation where the planner knows about expected damages in each region but does not know about expected costs. This final scenario may be most comparable to current practice, where total emissions for an area are determined based on the goal of achieving a specified air quality standard.

Previous studies, as noted, focused on the comparison of a price instrument and a quantity instrument in these cases. The wide-area trading here corresponds to the price instrument of previous studies. In the limit, as sub-regions become individual firms, the sub-regional trading programs here become quantity instruments. The contribution of this effort will be on whether the intermediate cases provide additional benefits, and on how permits are initially allocated affects the efficiency of wide-area versus local trading.

Case 1: Marginal benefits = marginal costs for each firm. If the social planner knows each firm's marginal benefit and marginal cost functions, maximizing net benefits from each firm produces $Q_i^* = \frac{A_1 + X_i - C_1 - Z_i}{2(A_2 + C_2)}$. Net benefits (NB) of abatement from each firm *i* are then

$$NB_i = (A_0 - C_0) + \frac{(A_1 + X_i - C_1 - Z_i)^2}{4(A_2 + C_2)}$$

The expected (average) net benefit (ENB) across all firms thus becomes

$$ENB = (A_0 - C_0) + \frac{(A_1 - C_1)^2 + E(X - Z)^2}{4(A_2 + C_2)}$$

In the rest of this paper, this result will be called ENB*. In this case, trading makes no sense, because each firm's level of abatement is determined optimally, and there are no gains from changing any firm's allocation of abatement. This case thus reflects the highest level of net benefits possible.

Case 2: Expected marginal benefits = expected marginal costs in each region. Now, the social planner is considering whether to permit wide-range marketable permits or localized marketable permits. Each sub-region is indexed by I. Consider first the case of localized permit trading. The planner knows that each firm will set its marginal cost of abatement equal to the permit price P_I, which will vary by region. Thus, $C_1 + Z_i + 2C_2Q_i = P_I$, or $Q_i = \frac{P_I - C_1 - Z_i}{2C_2}$. Net benefits (NB) of this system for firm *i* are therefore:

$$NB_i = (A_0 - C_0) + (A_1 + X_i - C_1 - Z_i)\,\frac{P_I - C_1 - Z_i}{2C_2} - (A_2 + C_2)\,[\frac{P_I - C_1 - Z_i}{2C_2}]^2.$$

The planner can find the optimal permit price, and thus the optimal number of permits for this sub-region, by (1) finding the expected net benefits for a firm in the sub-region, since the expected net benefits for a firm are just total net benefits divided by the number of firms; (2) maximizing the expected net benefits function with respect to P_I, to find the optimal price; (3) determining how much abatement (Q) is associated with that price; and (4) calculating expected net benefits for a firm in that sub-region when each firm chooses its optimal Q_i. Note that the expected values for X_i and Z_i in sub-region I (denoted E_IX and E_IZ) are not necessarily 0: any sub-region may have either costs or benefits of abatement either higher or lower than the overall average. This process yields

$$P_I^* = \frac{C_2(A_1 + E_I X) + A_2(C_1 + E_I Z)}{A_2 + C_2}$$

$$Q_i = \frac{A_1 + E_I X + \frac{A_2}{C_2} E_I Z - C_1}{2(A_2 + C_2)} - \frac{Z_i}{2C_2}$$

$$\equiv Q_I - Z_i/2C_2,$$

where Q_I is the nonvarying part of Q_i in sub-region I. Expected net benefits in sub-region I (ENB_I) are then:

$$ENB_I = (A_0 - C_0) + (A_1\text{-}C_1\text{+}E_IX\text{-}E_IZ)Q_I - (A_1\text{-}C_1)E_IZ/2C_2 - E_I(X\text{-}Z)Z/2C_2$$

$$- (A_2\text{+}C_2)[Q_I^2 \text{ -}2Q_IE_IZ/2C_2 - E_I(Z^2)/4C_2^2]$$

Let m(I) represent the proportion of all firms that are located in sub-region I. Then the expected value for any firm within the entire region of this localized trading scheme is the weighted expected value of all the sub-regions. The following identities are useful in deriving this value:

$$\Sigma_I m(I) = 1$$

$$\Sigma_I m(I)E_IX = \Sigma_I m(I)E_IZ = 0$$

$$\Sigma_I m(I)E_IXZ = E(XZ),\ \Sigma_I m(I)E_IX^2 = E(X^2),\ \Sigma_I m(I)E_IZ^2 = E(Z^2)$$

$\Sigma_I m(I)Q_I \equiv Q_A$ = average amount of abatement per firm in the whole region.

With these substitutions,

$$\Sigma_I m(I)ENB_I = (A_0\text{-}C_0) + (A_1\text{-}C_1)Q_A - \frac{E(X-Z)Z}{2C_2} - (A_2 + C_2)[Q_A^2 + \frac{E(Z^2)}{4C_2^2}] +$$

$$\Sigma_I m(I) \frac{(A_2 E_I Z + C_2 E_I X)^2}{4(A_2 + C_2)C_2^2}$$

With ENB* the solution to Case 1, this value can also be written as

$$\Sigma_I m(I) ENB_I = ENB^* - \frac{E(A_2 Z + C_2 X)^2}{4(A_2 + C_2)C_2^2} + \Sigma_I m(I) \frac{(A_2 E_I Z + C_2 E_I X)^2}{4(A_2 + C_2)C_2^2}$$

Because $E[G^2] > [E(G)]^2$ by Jensen's Inequality (with $G = A_2Z + C_2X$), net benefits are reduced from Case 1.

With full trading across the region, there is only one region I, and $E_IX = E_IZ = 0$. Thus,

$$P_{\text{Full Trading}}^* = \frac{C_2 A_1 + A_2 C_1}{A_2 + C_2}$$

$$Q_i = \frac{A_1 - C_1}{2(A_2 + C_2)} - \frac{Z_i}{2C_2}$$

$$\equiv Q_A - Z_i/2C_2,$$

$$ENB_{\text{Full Trading}} = (A_0 - C_0) + (A_1 - C_1)Q_A - \frac{E(X-Z)Z}{2C_2} - (A_2 + C_2)[Q_A^2 + \frac{E(Z^2)}{4C_2^2}]$$

$$= ENB^* - \frac{E(A_2 Z + C_2 X)^2}{4(A_2 + C_2)C_2^2}$$

The expected gains from regional trading relative to full trading are therefore:

$$\Delta_{\text{Partial - Full}} = \frac{\sum_I m(I)[A_2 E_I Z + C_2 E_I X]^2}{4(A_2 + C_2)C_2^2} > 0 .$$

In this case, where the optimal amount of pollution is already allocated to sub-region I, it is always more desirable to limit trading to local areas than to allow long-distance trading. Long-distance trading by definition ignores local variations. Because, within each sub-region, marginal benefits are set equal to marginal costs and the initial number of permits in each region is optimized for that region, it is impossible to do better by allowing wider trading.[2] This difference goes to zero when marginal damages are constant and do not vary across regions ($A_2 = 0$ and $\Sigma_I m(I) E_I X^2 = E_I X^2 = 0$): in that case, the location of emissions does not matter, and region-wide trading will provide the same net benefits as partial trading.

Case 3: Permits are assigned based on the planner assuming no regional variation in expected benefits or costs. The social planner only knows the total-area distributions for X and Z, not the variation of those distributions across sub-areas. Thus, the planner maximizes net benefits for a representative firm and derives Q_i, then takes the expectation of that value:

$$Q_i^* = \frac{A_1 + X_i - C_1 - Z_i}{2(A_2 + C_2)}; \ E(Q_i) = \frac{A_1 - C_1}{2(A_2 + C_2)} \equiv Q_A$$

In region I, let M(I) be the number of firms rather than the proportion. In region I, a total of $M(I)Q_A$ permits are allowed: that is, the planner hands them out to regions based on average acceptable emissions. The firms within that region will minimize abatement costs subject to permits equaling that sum. The Lagrangian for this problem is

$$L(Q_i, P_I) = \Sigma_{i=1,M(I)}[C_0 + (C_1 + Z_i)Q_i + C_2 Q_i^2] + P_I[M(I)Q_A - \Sigma_{i=1,M(I)} Q_i]$$

FOC: $C_1 + Z_i + 2C_2 Q_i = P_I$

$$M(I)Q_A = \Sigma_{i=1,M(I)} Q_i$$

Combining these gives

$$P_I = C_1 + 2C_2 Q_A + E_I Z$$

$$Q_i = Q_A + (E_I Z - Z_i)/(2C_2).$$

Let $Q_I = Q_A + (E_I Z/2C_2)$. Then $Q_i = Q_I - Z_i/2C_2$.

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[2] This result is comparable to findings by Mendelsohn in equations (6) and (9).

The following uses the procedure outlined previously: net benefits for a firm *i* in region I are calculated using Q_i, and the expectation of that term is taken to get the average net benefit in region I (ENB_I):

$$ENB_I = (A_0 - C_0) + [A_1 - C_1 + E_I X + (A_2/C_2)E_I Z]Q_I - (A_1 - C_1)(E_I Z)/2C_2 - E_I[XZ]/2C_2$$

$$+ (C_2 - A_2)[E_I(Z^2)]/4C_2^2 - (A_2 + C_2)[Q_I]^2$$

$$\Sigma m(I)ENB_I = (A_0 - C_0) + (A_1 - C_1)Q_A - (A_2 + C_2)[(Q_A)^2 + \frac{E(Z^2)}{4C_2^2}] - \frac{E(X-Z)Z}{2C_2}$$

$$+ \Sigma m(I)\{\frac{(E_I X)(E_I Z)}{2C_2} + \frac{(A_2 - C_2)(E_I Z)^2}{4C_2^2}\}$$

$$= ENB^* - \frac{E(A_2 Z + C_2 X)^2}{4(A_2 + C_2)C_2^2} + \Sigma m(I)\{\frac{(A_2 E_I Z + C_2 E_I X)^2}{4(A_2 + C_2)C_2^2} - \frac{(E_I X - E_I Z)^2}{4(A_2 + C_2)}\}$$

Net benefits are again lower than Case 1. They are also lower than in Case 2, by the last term in this equation, which is unambiguously negative. Because the planner has less information about how to allocate permits initially, the number of permits in each sub-region is likely to be more wrong than in Case 2.

Expected net benefits of full trading under this scheme are the same as before, since they are calculated in the same way. Thus, the expected gains from regional trading relative to full trading are:

$$\Delta_{Partial - Full} = \Sigma m(I)\{\frac{(E_I X)(E_I Z)}{2C_2} + \frac{(A_2 - C_2)(E_I Z)^2}{4C_2^2}\}$$

Alternatively, this difference can be written as:

$$\Delta_{Partial - Full} = \Sigma_I m(I)\{\frac{(A_2 E_I Z + C_2 E_I X)^2}{4(A_2 + C_2)C_2^2} - \frac{(E_I X - E_I Z)^2}{4(A_2 + C_2)}\}$$

When written this way, the first term is clearly positive, while the second term is clearly negative, demonstrating that either partial or full trading can be preferable in this scenario

Let V(Z) be the variance across regions with respect to the average Z within a region, and W(Z,X) be the covariance across regions with respect to the regional averages of Z and X. This difference can be rewritten as

$\Delta_{Partial - Full} = W(Z, X)/(2C_2) + (A_2 - C_2)V(Z)/(4C_2^2)$.

In this case, either permitting trading only in sub-regions (partial trading) or trading across the entire region (full trading) can have greater net benefits. The critical factors are the covariance between marginal benefits (MB) and marginal costs (MC), and the relative slopes of the MB and MC curves. This case produces essentially the same result as Weitzman, Mendelsohn, and Stavins.

The variation in marginal benefits does not affect the result directly; instead, it only appears through the covariance term. Wider trading possibilities will tend to equalize marginal costs across the region and decrease pollution where marginal costs of control are low. Suppose MB and MC are positively correlated with each other. Then low MC of abatement is associated with low MB of abatement. Under wider trading, these areas will have less pollution, and the lower pollution is not valued very highly. At the same time, areas with high control costs and high benefits of abatement will be permitted to have greater pollution, thus creating a "hot spot." Thus, positive covariance between MB and MC tends to make more localized pollution trading a socially preferable policy. In contrast, if MC and MB are negatively correlated, then increasing trading attracts more abatement to low-MC, high-MB areas, where increased abatement increases efficiency. Thus, it makes sense that covariance and the difference move together.

The previous authors found that positive covariance tended to favor regulatory standards. Because, in the limit, a localized permit scheme becomes a standard for each firm, this result is consistent with previous findings.

Additionally, variance in marginal costs has either a positive or negative effect, depending on whether the slope of the MB or MC curve is steeper. Greater variation in MCs results from steeper MCs; if MCs are constant, there is no advantage to trading. If MB is constant ($A_2 = 0$), steeper MC implies a greater advantage for full trading (excluding, for now, the covariance effect), due to the greater cost reductions from wider-area trading. If MB is steeper than MC, then the variation in MB makes hot spots a more serious problem. In this case, trading should be kept more local.

Case 4: Regional permit allocations are based on local marginal damages. Now the planner sets a different quantity for each region, based only on air quality.

$$Q_i^* = (A_1+X_i-C_1-Z_i)/2(A_2+C_2);\ E(Q_i) = (A_1+E_IX-C_1)/2(A_2+C_2) \equiv Q_{AI},$$

where Q_{AI} takes into account variation in the marginal benefits of abatement but does not consider variation in marginal costs. This scenario is intended to reflect the regulatory requirement that the ambient air quality standard be achieved in all locations.[3] The regulator is assumed not to be interested in, or not able to observe, variations of Z by region. For that reason, Q_{AI} is independent of Z. When firms trade their permits within region I, each firm's emissions will be

$$Q_i = Q_{AI} + E_IZ/2C_2 - Z_i/2C_2.$$

[3] It is of course possible (and in some cases, such as national parks, required) for areas to overcomply with the national ambient air quality standards. If that situation applied in this model, we assume the regulator would adjust the level of E_IX in setting the permitted levels of emissions.

Define $Q_I = Q_{AI} + E_I Z/2C_2$, making $Q_i = Q_I - Z_i/2C_2$, and define $Q_A = \Sigma_I m(I)Q_{AI}$ as the total number of permits in the region. Note that, by substituting in the definition of Q_{AI} from above,

$$Q_I = [(A_1+E_I X-C_1)C_2 + (A_2+C_2)E_I Z]/[2C_2(A_2+C_2)]$$

The same procedure is used as before to produce

$$ENB_I = (A_0-C_0) + [A_1-C_1+E_I X + (A_2/C_2)E_I Z]Q_I - (A_1-C_1)(E_I Z)/2C_2 - E_I[(X-Z)Z]/2C_2$$
$$- (A_2+C_2)\{[E_I(Z^2)]/4C_2^2 + Q_I^2\}$$

$$\Sigma m(I)ENB_I = (A_0-C_0) + (A_1-C_1)Q_A - \frac{E(X-Z)Z}{2C_2} - (A_2 + C_2)\frac{E(Z^2)}{4C_2^2}$$

$$+\Sigma m(I)Q_I\{E_I X + A_2 E_I Z/C_2 - (A_2+C_2)Q_I\}$$

Using the definition of Q_I above, this equation can be rewritten as

$$\Sigma m(I)ENB_I = (A_0-C_0) + (A_1-C_1)Q_A - \frac{E(X-Z)Z}{2C_2} - (A_2 + C_2)\frac{E(Z^2)}{4C_2^2} - \frac{(A_1-C_1)^2}{4(A_2+C_2)}$$

$$+ \Sigma m(I)\{ \frac{(E_I X)^2}{4(A_2+C_2)} + \frac{A_2(E_I X)(E_I Z)}{2C_2(A_2+C_2)} + \frac{(A_2-C_2)(E_I Z)^2}{4C_2^2} \}$$

$$= ENB^* - \frac{E(A_2 Z + C_2 X)^2}{4(A_2+C_2)C_2^2} + \Sigma m(I)[\frac{(A_2 E_I Z + C_2 E_I X)^2}{4(A_2+C_2)C_2^2} - \frac{(E_I Z)^2}{4(A_2+C_2)}]$$

Again, this case has lower net benefits than Case 2, by the last term. Its net benefits are higher than in Case 3, indicating that it is better to use available information about marginal benefits when marginal costs information is not available, than to use neither.

Because the expected net benefits of full trading are still the same as above,

$$\Delta_{Partial-Full} = \Sigma m(I)[\frac{(E_I X)^2}{4(A_2+C_2)} + \frac{A_2(E_I X)(E_I X)}{2C_2(A_2+C_2)} + \frac{(A_2-C_2)(E_I Z)^2}{4C_2^2}]$$

$$= \Sigma m(I)\left[\frac{(A_2E_IZ + C_2E_IX)^2}{4(A_2 + C_2)C_2^2} - \frac{(E_IZ)^2}{4(A_2 + C_2)}\right]$$

Comparing the first version to the result of Case 3, there is one new term (the first), and the coefficient on the second is different. Unsurprisingly, the effects of differences in marginal benefits now play a greater role, including a direct effect previously absent. To the extent that marginal benefits differ across regions, the first term makes partial trading more desirable. The second term (the covariance term) behaves in the same way as in Case 3: positive covariance argues for more localized trading, while negative covariance makes the benefits wider-scale trading higher. The third term, representing the variation in marginal costs of abatement, once again produces ambiguity due to the relative slopes of MB and MC.

Alternatively, using the second version of the difference, as in Case 3, the first term is clearly positive, while the second term is clearly negative. Here, whether the difference is smaller or larger than in Case 3 depends on the magnitude of the variance of X and the magnitude and covariance of X and Z. If X and Z are negatively or weakly positively correlated, Δ (the preference for partial over full trading) will be greater in Case 4. As discussed for Case 3, positive correlation between MB and MC exacerbates the "hot spot" problem, while negative correlation makes wider-area trading more acceptable. When MB and MC are positively correlated, local trading under Case 4 is more likely to have greater restrictions on pollution in the high-MB areas. Since those are also high MC areas, Case 4 is likely to be too restrictive in areas with high MB, compared to Case 3 (where neither MB nor MC are involved in the initial allocation of permits).

The following summarizes the results presented for these four cases.

Case 1: $MB_i = MC_i$

$$Q_i = \frac{A_1 + X_i - C_1 - Z_i}{2(A_2 + C_2)}$$

$$\Sigma_I m(I) ENB_I = (A_0 - C_0) + \frac{(A_1 - C_1)^2 + E(X - Z)^2}{4(A_2 + C_2)} \equiv ENB^*$$

$ENB_{\text{Full Trading}}$ is irrelevant in this case, because trading cannot happen.

$\Delta_{\text{Partial - Full}}$ is also irrelevant.

Case 2: $E(MB_I) = E(MC_I)$

$$Q_i = \frac{A_1 + E_I X + {}^{A_2}\!/\!_{C_2}\, E_I Z - C_1}{2(A_2 + C_2)} - \frac{Z_i}{2C_2}$$

$$\Sigma_I m(I) ENB_I = ENB^* - \frac{E(A_2 Z + C_2 X)^2}{4(A_2 + C_2)C_2^2} + \Sigma_I m(I) \frac{(A_2 E_I Z + C_2 E_I X)^2}{4(A_2 + C_2)C_2^2}$$

$$ENB_{\text{Full Trading}} = ENB^* - \frac{E(A_2 Z + C_2 X)^2}{4(A_2 + C_2)C_2^2}$$

$$\Delta_{\text{Partial - Full}} = \Sigma_I m(I) \frac{(A_2 E_I Z + C_2 E_I X)^2}{4(A_2 + C_2)C_2^2} > 0$$

Case 3: Planner assumes $E_I Z = E_I X = 0$

$$Q_i = Q_A + \frac{E_I Z - Z_i}{2C_2} = Q_I - \frac{Z_i}{2C_2}$$

$$\Sigma_I m(I) ENB_I = ENB^* - \frac{E(A_2 Z + C_2 X)^2}{4(A_2 + C_2)C_2^2} + \Sigma m(I) \{ \frac{(A_2 E_I Z + C_2 E_I X)^2}{4(A_2 + C_2)C_2^2} - \frac{(E_I X - E_I Z)^2}{4(A_2 + C_2)} \}$$

$$ENB_{\text{Full Trading}} = ENB^* - \frac{E(A_2 Z + C_2 X)^2}{4(A_2 + C_2)C_2^2}$$

$$\Delta_{\text{Partial - Full}} = \Sigma m(I) \{ \frac{(E_I X)(E_I Z)}{2C_2} + \frac{(A_2 - C_2)(E_I Z)^2}{4C_2^2} \}$$

$$= \Sigma_I m(I)\{\frac{(A_2E_IZ + C_2E_IX)^2}{4(A_2+C_2)C_2^2} - \frac{(E_IX - E_IZ)^2}{4(A_2+C_2)}\}$$

$$= W(X,Z)/2C_2 + (A_2\text{-}C_2)V(Z)/4C_2^2$$

Case 4: Planner assumes $E_IZ = 0$

$$Q_i = Q_{AI} + \frac{E_IZ - Z_i}{2C_2} = \frac{(A_1 + E_IX - C_1)C_2 + (A_2+C_2)E_IZ}{2C_2(A_2+C_2)} - \frac{Z_i}{2C_2}$$

$$\Sigma m(I)ENB_I = ENB^* - \frac{E(A_2Z + C_2X)^2}{4(A_2+C_2)C_2^2} + \Sigma m(I)[\frac{(A_2E_IZ + C_2E_IX)^2}{4(A_2+C_2)C_2^2} - \frac{(E_IZ)^2}{4(A_2+C_2)}]$$

$$ENB_{\text{Full Trading}} = ENB^* - \frac{E(A_2Z + C_2X)^2}{4(A_2+C_2)C_2^2}$$

$$\Delta_{\text{Partial -Full}} = \Sigma m(I)[\frac{(E_IX)^2}{4(A_2+C_2)} + \frac{A_2(E_IX)(E_IX)}{2C_2(A_2+C_2)} + \frac{(A_2-C_2)(E_IZ)^2}{4C_2^2}]$$

$$= \Sigma m(I)[\frac{(A_2E_IZ + C_2E_IX)^2}{4(A_2+C_2)C_2^2} - \frac{(E_IZ)^2}{4(A_2+C_2)}]$$

$$= V(X)/4(A_2+C_2) + A_2W(X,Z)/2C_2(A_2+C_2) + (A_2\text{-}C_2)V(Z)/4C_2^2$$

Summary. Ideally, a planner would set the marginal benefits of abatement equal to the marginal costs for every firm on an individual basis (Case 1 here). Of course, the information and transactions costs for that procedure are enormous. Even the idea of transfer coefficients, to account for differences in marginal damages in trades, has rarely been implemented. Instead, marketable permit schemes are typically arranged so that permits are traded on a one-for-one basis, but the trades are often geographically restricted to areas where it is likely that the effects of emissions from different sources are similar. If trading were opened up to a larger region, the costs of abatement would probably drop, but the likelihood of a pollution hot spot also increases.

How marketable permits are allocated across sub-regions has a significant influence over the decision on whether partial trading is preferred to full trading. If localized trading is optimally designed, so that expected marginal benefits within each region equals expected marginal costs (Case 2), opening up trading more widely will reduce net benefits, since trading was originally optimally designed. Rarely do planners have this level of information, or even the regulatory authority, to assign permits in each region based on expected benefits and costs within a region. Instead, they may assign permits based only on region-wide averages (Case 3), or on consideration only of local abatement benefits (Case 4). Both these cases reduce net benefits from either Case 1 or Case 2, but they also have lower informational requirements.

In the latter two cases, because permits are initially allocated to regions in a manner that does not attempt optimality, it is possible for wider-area trading to increase societal benefits. In particular, having negatively correlated marginal benefits and marginal costs, marginal cost curves steeper than marginal benefit curves, and (in Case 4) small or no variation in marginal benefits will lead to wider-area trading being more desirable than localized trading. Whether those conditions hold is, of course, an empirical matter. The following section examines the case of ozone control in California's San Joaquin Valley to see if wider-area trading is likely to increase net social benefits over a localized scheme.

Ozone and the San Joaquin Valley of California

This case study draws on Kim's study of the San Joaquin Valley (SJV) of California, a region that produces about 60% of California's total crop production in value (California Department of Food and Agriculture). Figure 1 identifies the location of counties in the SJV. Ozone levels reached as high as 0.17 parts per million (ppm) in 1990, substantially exceeding the then-current health-based federal and state standards of 0.12 ppm and 0.09 ppm, respectively.[4] Crop damage occurs at ozone concentrations even lower than those standards: according to the California Air Resource Board (CARB, 1987), ozone-sensitive crops such as onions, lemons, beans, grapes, oranges, and cotton could experience yield losses at a 0.04 ppm 12-hour ozone standard (roughly equivalent to the 0.09 ppm 1-hour ozone standard[5]). Thus, crop yields in some areas of California may be affected even if the current ozone standard is attained.

Ozone is formed through the interaction of reactive organic gases (ROG) and nitrogen oxides (NO_X) in the presence of sunlight. Ozone causes a variety of respiratory complications, though these are typically considered transitory; any chronic or long-term effects of ozone are not well documented at this point. As an oxidant, ozone interferes with plant photosynthesis and thus inhibits growth. Indeed, some of the most highly valued crops grown in the SJV are among the most ozone-sensitive. Kim's analysis included development of marginal cost of abatement curves for 97 ROG-emitting plants with 250 sources and 225 NO_X-emitting plants with 822 sources (some plants have multiple emission sources (stacks)) for eight counties in the SJV. This study also developed estimates of the benefits to health and agricultural production associated with

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[4] The 0.17 ppm observation is the peak concentration measured with a one-hour average. The primary federal ozone standard was amended effective September 16, 1997 to be "an 8-hour standard at a level of 0.08 parts per million (ppm) with a form based on the 3-year average of the annual fourth-highest daily maximum 8-hour average O3 [ozone] concentrations measured at each monitor within an area" (U.S. Environmental Protection Agency (EPA), p. 38856). (That standard has now been reviewed in federal court and is not applicable at the time of this writing.) The 0.12 ppm standard, based on a one-hour average, is not directly comparable to the new 0.08 ppm standard. Because this analysis was originally conducted using the previous standard, the results obtained here do not relate directly to the new standard. For comparison, setting the standard at 0.09 with the new form of averaging "represents the continuation of the present level of protection" (EPA, p. 38858).

different levels of ozone reduction. That study estimated the optimal level of pollution between 0.12 and 0.14 parts per million (ppm), though the benefits and costs varied widely across sub-regions.

The San Joaquin Abatement Cost Model (SJAC). The cost side of the SJAC depends upon cost of abatement functions for each firm, i, of the form

$$TC(Q_i) = L_i \log (1-Q_i/E_i)$$

where L_i is a negative constant, E_i is current emissions, and Q is abatement. Kim derived these cost functions for the 822 NOX sources and 249 ROG sources from technical considerations and data from the California Air Resources Board (CARB). Kim also included mobile sources; they are included here as well, taken directly from Kim's work. Marginal cost is given by:

$$MC = -L_i /(E_i - Q_i).$$

Since firms in a given trading region will trade until their MCs are the same and equal to the price offered by that region for pollution reduction, $P = MC(Q_i)$. Similar to the theory section, let E_I be the sum of E_i for firms in county I, with Q_I and L_I defined analogously. The abatement supply function for region I is thus

$$Q_I = E_I + L_I/P.$$

A trading region, R, is a set of counties whose firms may trade freely with each other. Therefore P is the same everywhere in R. Let w be the fraction by which pollution is to be reduced in the region. Thus total abatement in the region equals w times the total original emissions,

$$\Sigma_R Q_I = w \Sigma_R E_I.$$

[5] The 12-hour ozone standard is the average of the peak ozone concentration per hour between 9:00 AM and 9:00 PM.

Summing the supply curve for the region and using the identity above gives the regional price for pollution:

$$P_R = -\Sigma_R L_I /[(1\text{-}w)\ \Sigma_R E_I]$$

Thus the amount of abatement in each county in a region is

$$Q_I^* = E_I + L_I/P_R,$$

and the amount of abatement for each firm in the region is

$$Q_i^* = E_I + L_i/P_R.$$

Since

$$1\text{-}\ Q_i/E_i = -L_i/(P_R\ E_i),$$

the total cost (TC) of abatement for a firm in region R is

$$TC(Q_i^*) = L_i \log(-L_i/(P_R\ E_i)),$$

and total cost of abatement in county I which is in region R is

$$\Sigma_I\ TC(Q_i^*). = \Sigma_I\ L_i \log(-L_i/(\ E_i)) - L_I \log(P_R).$$

The first term on the right-hand side of the TC equation is a constant, so differences in trading regime costs are all in the term $- L_I \log(P_R)$.

For comparison consider the case of no trading whatsoever. Now each firm is required to abate $Q_i = w\ E_i$. Making the substitution for Q makes the total cost function

$$TC(wE_i) = L_i \log(1\text{-}w),$$

and the costs for region I are

$$\Sigma_I\ TC(wE_i) = L_I \log(1\text{-}w)$$

The total costs of abatement are the sum of the regional costs. To achieve an overall reduction in pollution of w, Kim calculated separately the percent reductions in NO_X and ROG for stationary sources, since stationary sources represent different proportions of production of those pollutants. Here, both ROG and NO_X from stationary sources and from mobile sources are reduced by the same proportion.[6] As a result, the conclusions from this work are not exactly comparable to those in Kim or Kim, Helfand, and Howitt. *Benefits*. The SJAC model accounts for benefits to crop production and to human health from ozone reduction. This paper uses the mean of the highest and lowest of the benefit numbers cited in Kim. Health benefits are in millions of dollars of benefit, by county and by ppm of ozone.

The SJAC model derives its estimates of crop losses from ozone in a three-step procedure. First, existing studies provided the yield-reducing effects of ozone by crop. Then the supply functions in the California Agricultural and Resource Model (CARM), a multimarket equilibrium model for all of California agriculture, were modified to reflect the supply reduction from ozone. Lastly, CARM was run with different levels of ozone by county to determine changes in producer and consumer surplus by CARM region as a function of ozone standards. While it is always good for agriculturists and consumers to reduce smog in the SJV, producers in other regions can incur losses from higher San Joaquin production.

In this paper we took the results from the CARM runs and produced a table of them as follows. First we averaged the results for high and low elasticity runs. Then we assigned benefits from CARM regions to counties based upon the counties' shares in agricultural production. Lastly we assigned consumer surplus benefits and other regions' producer surplus losses to the counties based upon their production shares. The result

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[6] When trading is permitted across counties in this study, the percent reduction in pollution is calculated as a weighted average of the (traded) reductions from stationary sources and the (untraded) reductions in mobile sources in each county.

was a table of benefits, by county and by ppm reduction. This table was added to the table for health benefits to get a table of benefits by ppm by county.

There is an underlying assumption here that pollution emitted in one county does not make a large difference in another county's air quality. While the SJV and its more important counties are quite large, this assumption is not literally true. There is not currently information to permit a more refined model of air pollution incidence.

Fresno and Kern: Two Important Counties. Fresno County is an agriculturally important county and has the largest population in the Valley. Kern, while also agriculturally important, has significant oil production as well. The oil industry is both polluting and relatively cheap to clean up. An examination of the marginal cost and marginal benefit curves for these counties gives some idea of the potential for trading. The marginal cost for abating NO_X for these two counties, shown in Figure 2, makes clear that it is much cheaper to abate NO_X in Kern than in Fresno County. A trading regime with only these two counties would result in all the abatement in Kern County. Figure 2 also includes a discrete approximation of marginal benefits; it indicates that the marginal benefits of abating are much higher in Fresno than Kern. Therefore a trading regime, by allocating rollbacks to the county that can cut back pollution more cheaply, would miss the opportunity to abate where clean air is more valuable.

The Number of Contiguous Trading Regions. In developing trading sub-regions, we consider only contiguous counties. Contiguous trading regions make sense from the point of view of air mixing, as the counties in this study do not form totally separate air-sheds. If contiguous counties trade, it is most likely that the benefits of cleaner air will be internal to the trading region. From a regulator's point of view, it also seems unlikely a county interior to a trading region could be excluded from a trading scheme. Finally, because the number of possible contiguous trading regions is smaller than the number of arbitrary regions, the computations become more feasible.

Using a recursive algorithm, we can show that there are 338 ways to divide the 8 counties in the SJV into contiguous regions. For each of the 8 counties, we first construct the edge set, the set of counties adjacent to a given county. To find the possible ways of partitioning the 8 counties into contiguous regions, we recursively construct the regions for first 1, then 2, then 3, etc. counties. For instance, if we start with Kern (county 16 on Figure 1), there is only one trading region with just Kern County. With the addition of county 15, Kings, there are two possibilities: {{Kings}, {Kern}} and {{Kings,Kern}}. (The outer braces indicate a set of trading regions and the inner braces contain the counties in the trading region.) In the first case, there is no trading since each trading region has one county; in the second there is trading. When we add Fresno (number 10 on the map), since Fresno is only adjacent to Kings, there is one less possibility for trading because of adjacency. The trading regions, are {{Kings}, {Kern}, {Fresno}}, {{Kings, Kern, Fresno}}, {{ Kings, Kern}, {Fresno}}, {{Kings, Fresno}, {Kern}}. Continuing in this manner yields the list of 338 possible ways for trading to occur in the SJV.

The Optimal Trading Regions. To find the optimal trading regions we examined two cases, one with a 20% reduction in emissions and the other with a 60% reduction. We also consider intermediate cases, to estimate what the optimal pollution levels might be under alternative policies.

For each of the 338 possible ways of trading, we computed the price in each of the trading regions as described above. Using that price we computed the level of abatement in each county, the cost of abatement, and the benefits of abatement. The trading region that had the greatest net benefits was the selected trading region. We compared that region to the autarky solution (trading only within counties) and to the complete trading solution.

The optimal trading regions are given in the table below for both 20% and 60% cutbacks. There is one more trading region with a 20% cutback than a 60% cutback, possibly indicating that the effects of differences in marginal benefits is more significant with a smaller pollution reduction than with a larger reduction. When pollution is reduced more dramatically, differences in marginal costs may be more important than differences in marginal benefits, thus resulting in larger trading regions.

Table 1: Trading Regions under 20% and 60% Cutbacks

	Trading Regions under 20% Cutback	Trading Regions under 60% Cutback
Region 1	Kern and Kings County	Kern County
Region 2	Tulare and Fresno Counties	Kings, Tulare, Fresno, and Merced
Region 3	Madera County	Madera County
Region 4	Stanislaus and San Joaquin Counties	Stanislaus and San Joaquin
Region 5	Merced County	————

Table 2 gives the net benefits of the different trading regimes for different levels of cutbacks. Under either optimal trading or autarky, a 40% emissions reduction maximizes net benefits; if there is full trading, the current level of pollution is preferable to any cutbacks. Kim's study (conservatively) suggests the optimal pollution level as between 0.12 and 0.14 ppm, where the 0.13 ppm standard is associated with a 34% reduction in ROG and 53% reduction in NO_X. That study considered two scenarios: no trading, with all stationary and mobile sources reducing their emissions by a fixed percentage; or trading limited to within counties. Thus, these two studies show similar results for the optimal reduction in pollution, even though the rollbacks are handled slightly differently, and the trading regimes are not identical.

Table 2: Net Benefits of Different Trading Regimes with Different Proportions of Cutbacks (all values in $million).

Cutback proportion	0.1	0.2	0.3	0.4	0.5	0.6
Optimal Regions	$155.72	$156.18	$155.83	$157.79	$141.53	$69.87
Autarky	$106.55	$125.45	$130.74	$138.94	$127.54	$59.61
Full Trading	$142.43	$128.59	$100.61	$105.40	$103.54	$43.72

As shown in Table 3, the total benefits of abatement with optimal trading regions for the 20% cutback are $243 million, while the costs of abatement are $87 million. This solution has $31 million in additional benefits and $141,000 lower costs compared with autarky (no trading between counties). Here the advantages of trading are driven by the inefficiency of a uniform pollution rollback, since gains from cost reductions are not very large. It is also notable that the most different regions, Kern and Fresno, are not permitted to trade with each other.

Table 3: Benefits and Costs of Alternative Trading Regimes (all values in $million)

	Optimal Trading	Optimal minus Autarky	Full Trading minus Autarky
20% Cutback			
Benefits	242.9222	30.58456	1.855393
Costs	86.74487	-0.14118	-1.279400
B-C	156.1773	30.72574	3.134793
60% Cutback			
Benefits	496.5544	9.987827	-17.1676
Costs	426.6835	-0.27379	-1.2794
B-C	69.87091	10.26162	-15.8882

Allowing all counties to trade with each other gives up most of the benefits relative to limited trading. Benefits of full trading relative to autarky are only $1.9 million, but cost savings increase to $1.3 million. Allowing full trading is better than autarky in this case but gives up 90% of the achievable benefits.

A 60% cutback has even greater benefits than the 20% cutback. The trading regions identified in Table 1 still have higher benefits and lower costs than permitting no trading, though the net benefits are smaller than under the 20% cutbacks. Here, though, full trading has lower net benefits than autarky. Although costs are $1.3 million lower under full trading, benefits are reduced by $17 million. As the permissible level of pollution becomes small, more sources need to be controlled, and gains from trading are reduced.

Table 4 gives estimated pollution levels for each county under these scenarios. Autarky with a 20% cutback achieves a standard of 0.152 ppm. With limited trading Kern, San Joaquin, and Fresno are only slightly more polluted, while Kings, Stanislaus and Tulare are noticeably less polluted, than without trading. The numbers are not so different as to raise severe questions about political acceptability or the exact pattern of effluent dispersion. With full trading, the range of ozone concentration among the counties is quite wide, from 0.144 to 0.176. Fresno and Madera end up with more ozone than before the cutback. This outcome is unlikely to be politically acceptable.

Table 4: Ozone Concentration (ppm) under Different Trading Regimes

	Kern	Kings	Tulare	Fresno	Merced	Madera	Stanislaus	San Joaquin
With 20% cutback								
Optimal	0.15234	0.14801	0.13701	0.15348	0.1522	0.1522	0.14244	0.15697
Autarky	0.1522	0.1522	0.1522	0.1522	0.1522	0.1522	0.1522	0.1522
AllTrade	0.14763	0.14458	0.14445	0.17646	0.15965	0.17388	0.14373	0.16005
With 60% cutback								
Chosen	0.11648	0.10932	0.10928	0.11847	0.11307	0.11648	0.1116	0.11887
Autarky	0.11648	0.11648	0.11648	0.11648	0.11648	0.11648	0.11648	0.11648
AllTrade	0.1142	0.11267	0.11261	0.12861	0.12021	0.12732	0.11225	0.12041

A 60% cutback achieves a 0.12 standard under autarky as well as under the optimal trading regime. Under full trading, Fresno and Madera (and Merced barely) exceed that 0.12, with somewhat lower pollution in the remaining counties. The level of variation in pollution levels under full trading is not as large with a 60% cutback (about 0.01 ppm) as with a 20% cutback (about 0.03 ppm), again because more sources need to be controlled more fully under the 60% option.

In sum, the empirical evidence in the San Joaquin Valley suggests that optimal trading can have significant net benefits for society over autarky for a moderate level of pollution reduction, though those net benefits are reduced substantially as pollution reductions become more severe. Similarly, full trading appears to have benefits greater than those of autarky for a moderate level of pollution reduction, but autarky appears preferable to full trading under a greater pollution reduction. The variation in pollution levels, for carefully designed trading regions, is not very large, but the variation in pollution levels can be quite large when one-to-one trading is permitted across the full Valley.

The trading regions analyzed here were not developed to find the optimal level of pollution for each region; instead, as in Case 3 in the theoretical analysis, allowed pollution levels were dictated to regions based on the required pollution reduction. The empirical results are consistent with the theoretical finding that trading in limited areas can have greater net benefits than full trading, especially when sub-regions are designed to have the greatest net benefits for that level of pollution reduction. It also indicates that complete subdividing of regions (as represented by autarky in this case) is not socially optimal, also consistent with the theoretical result that net gains from partitioning are ambiguous. Future work should explore the consequences of other methods of assigning permits for the efficiency of different trading rules.

Conclusion

In how large a geographic area should pollution trading be permitted on a one-to-one basis? Ideally, one-to-one trading should only take place when marginal damages are the same for those in the market. Over larger areas, there can still be significant gains from trade due to greater diversity in marginal abatement costs, but the greater diversity in marginal benefits of abatement may make the net benefits of larger-area trading undesirable.

This paper has examined the effects of several different methods of allocating permits on the choice of subdividing trading regions compared to permitting wide-area trading. If permits can be allocated so that marginal benefits equal marginal costs in all sub-regions, it is always preferable to limit trading regions, since the sub-regions have pollution levels individually optimized. If permits are distributed in a less efficient fashion, though (here, either with no consideration of marginal benefits and costs in individual sub-regions, or with consideration only of marginal benefits in sub-regions), it is possible for either wide-area trading or for more localized trading to be optimal. The theoretical analysis shows that it is advantageous to use some information about sub-regions (such as consideration of marginal benefits but not marginal costs) rather than no information in developing the allocation of permits to each region, and that the variation of marginal costs, marginal benefits, and the covariance of marginal benefits and costs affect the desirability of more localized trading relative to wider-region trading.

The empirical analysis examined the case where pollution allocations were designed with no consideration of either marginal benefits or marginal costs. For the San Joaquin Valley of California, there are substantial net gains from permitting some counties to trade across county boundaries, as well as gains from not permitting trading across all county boundaries. Thus, this example illustrates the fact that complete subdivision may not be desirable, while complete trading is also not desirable.

For policy purposes, this paper suggests that how permits are initially allocated has a significant effect on both the overall efficiency of trading schemes and on the desirability of local vs. wide-area trading. If regulators have enough information to allocate permits within regions in a way that takes regional differences into account, limiting trades is more likely to be desirable than wide-area trading. With less information about regions, regulators have greater reason to think that there are advantages in some regional trading, but it is still not certain that wide-area trading is more desirable than limiting trading to small areas.

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Figure 1: Counties of California

1 Alameda
2 Alpine
3 Amador
4 Butte
5 Calaveras
6 Colusa
7 Contra Costa
8 Del Norte
9 El Dorado
10 **Fresno**
11 Glenn
12 Humboldt
13 Imperial
14 Inyo
15 **Kern**
16 **Kings**
17 Lake
18 Lassen
19 Los Angeles
20 **Madera**
21 Marin
22 Mariposa
23 Mendocino
24 **Merced**
25 Modoc
26 Mono
27 Monterey
28 Napa
29 Nevada
30 Orange
31 Placer
32 Plumas
33 Riverside
34 Sacramento
35 San Benito
36 San Bernardino
37 San Diego
38 San Francisco
39 **San Joaquin**
40 San Luis Obispo
41 San Mateo
42 Santa Barbara
43 Santa Clara
44 Santa Cruz
45 Shasta
46 Sierra
47 Siskiyou
48 Solano
49 Sonoma
50 **Stanislaus**
51 Sutter
52 Tehama
53 Trinity
54 **Tulare**
55 Tuolumne
56 Ventura
57 Yolo
58 Yuba

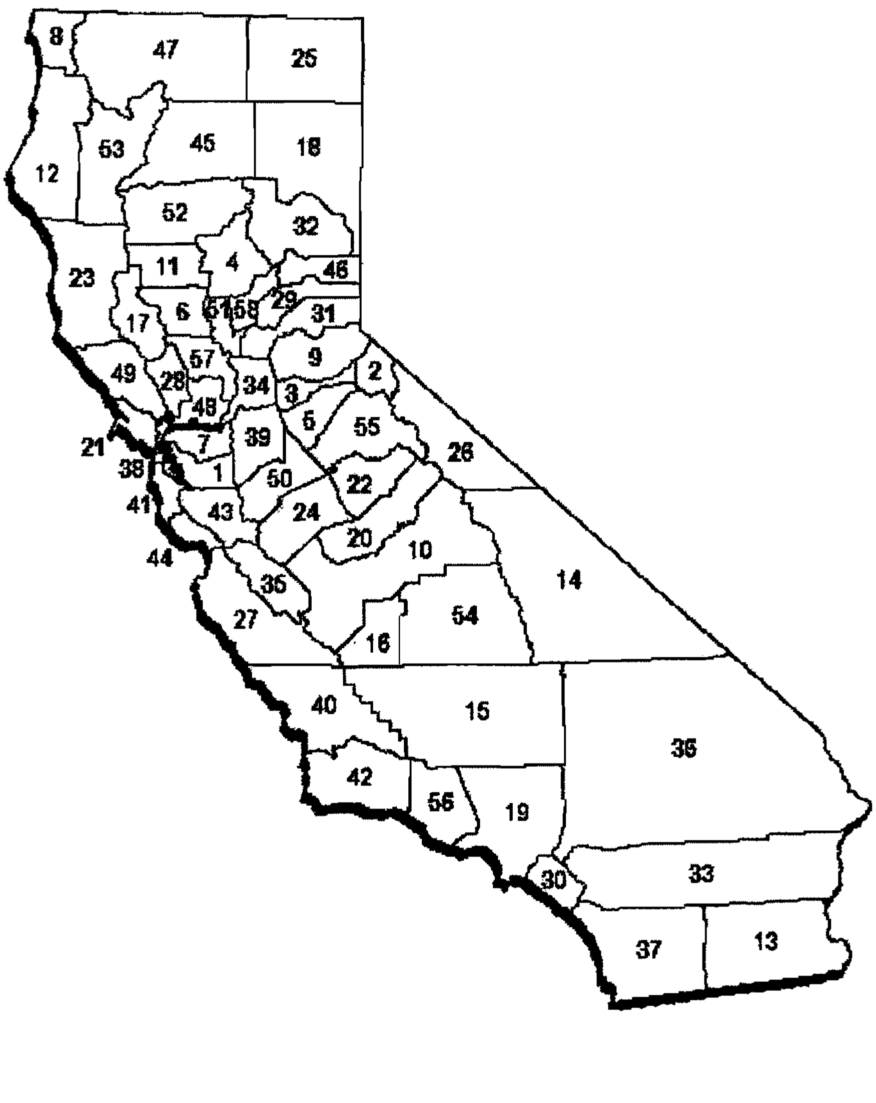

Figure 2: Marginal Benefits and Costs of Abatement for Nitrogen Oxides for Fresno and Kern Counties