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ABSTRACT

This study analyzes the ROG control costs of stationary sources in the San Joaquin Valley of California. The cost-effectiveness of market incentive approaches such as an uniform marketable permit system, localized marketable permit system and an ambient permit system as well as a traditional command-and-control approach are examined.
1. INTRODUCTION

Traditional emission command-and-control (CAC) approaches have been criticized as more costly than marketable emission permit systems to meet a required emission reduction or to achieve a desired air quality. In marketable permit systems, polluters with higher costs for emission control buy permits from polluters with lower costs, and as a result, total aggregate abatement costs can be reduced.

The most-effective permit system to achieve a desired air quality would be ambient permit system (APS) in which stationary sources can freely trade their emission permits based on their differentiated contribution to the same receptors. This approach, however, is not always taken into consideration because of its difficulty of obtaining spatial dispersion characteristics of emissions from stationary sources to receptors. Uniform marketable permit system (UMPS) is the least-cost strategy to meet a required reduction in total emissions. This system allows one-to-one permits trading under the assumption that all emission sources have the same impact on air quality in a region. A shortcoming of this system is that hot spots can be created after trading of emission permits from less polluted area to more polluted area in a region.

Localized marketable permit system (LMPS) allows free trading of their emission permits on a one-to-one basis as long as the sources located within same parts of a region, in which emissions are considered to have the same effects on the receptors. Although, not as cost-effective as APS due to limited possibility of permits trading, LMPS may result in significant cost savings.

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1 A receptor is a geographical area in which air quality is affected by the emission sources. For example, a city can be considered as a receptor.

2 Receptor sites that violate air quality standards.
savings from the traditional standards-based approaches and it also can considerably reduce the possibility that hot spots are created.

Many studies (Atkinson and Lewis, 1974; Atkinson and Tietenberg, 1982; Seskin, Anderson, and Reid, 1983; Hahn and Noll, 1983; Oates, Portney and McGartland, 1989; Schmalensee and Joskow, 1998) have found that marketable permit systems are more cost-effective than standard-based approaches in achieving the required emission reduction or the given air quality objectives.

Atkinson and Lewis, 1974, developed control cost data for particulate emission controls from 27 stationary sources in the St. Louis Air Quality Control Region (AQCR). They assumed that sources would install additional emission control devices that were compatible with the existing control measures to reduce further particulate emissions. The total additional cost of further emission reductions is equal to the sum of the annualized capital and installation costs plus the operating and maintenance costs of the additional control equipment. Finally, the constant marginal cost data were constructed by dividing the total additional costs by the total additional emission reductions in tons. These control cost data were also used by Atkinson and Tietenberg, 1982. They found that the state CAC policies to control air quality were six to ten times more costly than a cost-minimizing strategy.

Hahn et al., 1982, estimated the cost savings of the emission permit system for sulfur dioxide (SO₂) in the Los Angeles area. Their study identified a cost savings of 3-19% of CAC policy. Seskin, Anderson, and Reid, 1982, also used a mathematical model to examine the costs of meeting a prospective short-term standard for nitrogen dioxide (NO₂) under a range of alternative emission control strategies for stationary sources in the Chicago Air Quality Control Region.
Their analysis indicates that the more efficient emission control programs are much less costly than current CAC policies. They estimated that the annual control costs for the ambient permit system was $9 million, while CAC policy required $130 million to attain the same ambient standard.

Maloney and Yandle, 1984, examined Reactive Organic Gases (ROG) emission control cost functions for 543 sources in 52 plants of the DuPont Company. They assumed stacking technologies in which emission control devices were applied in sequence to reduce further emissions. The marginal emission control costs would be the costs incurred through the implementation of the additional control measures installed in sequence. By repeating these stacking processes, a group of emission control cost data and emission control levels would be constructed. Maloney and Yandle developed emission control cost functions for each source based on these data points through the application of econometric analysis. They estimated hydrocarbon pollution control costs under the alternative regulatory approaches of individual source or process standards, plant standards, and regionally marketable permits. Their study showed that the cost savings realized from a system which relied on marketable permits, when compared to source standards, ranged from 85% at the 60% abatement goal to a 29.5% savings for a 99% reduction of emissions.

Oates, Portney and McGartland, 1989, examined costs of controlling total suspended particulate (TSP) under two different policies: incentive based (IB) policy and CAC policy. They estimated that the marginal control costs of reducing TSP concentration to 100 µg/m³ TSP standard in Baltimore would be $32.7 million under IB policy, while the standard would cost $48.1 million under CAC policy. Schmalensee, et. al., 1998 estimated the total cost of reducing...
sulfur dioxide emissions by 3.9 million tons in 1995 was about 725 million, which was lower on the order of $225-375 million per year to CAC policies.

The California state policy directed at reducing ROG emissions from stationary sources has been largely on emission standards with limited use of emission permits. The current permit systems, however, have many restrictions on emission permit trading. For example, new sources are allowed to buy emission reduction credits only if they control their emissions to the LAER (lowest achievable emission rate) standard (Kim, 1994). Existing sources with significantly higher emission rates than the standards are now allowed to buy emission reduction credits without reducing their emissions to LAER standard (Kim, 1994). Each sources with different impacts on a regional air quality are often prevented from trading their spatially differentiated permits due to its complexity involved.

An alternative permit system which can provide cost-savings from the current system in the San Joaquin Valley of California would be LMPS with full permits transferability. All sources can freely trade their permits on a one-to-one basis if they locate in the same local areas. It would not significantly distort the effectiveness of APS because stationary sources are clustered into a few cities within which their emissions can be considered to have the same impact on air quality in the San Joaquin Valley. LMPS also can prevent hot spots from being created. Because of the spatial distribution of the cities in which stationary sources are clustered in the San Joaquin Valley which lies over about 400 miles long, one-to-one permits trading among sources across remote cities can easily create hot spots.

Although marketable permit systems are well known to meet emission reductions or air quality standards at lower costs than standard-based approaches, little information is available for
empirical comparison among different marketable permits designs at a regional level in terms of their cost-effectiveness and possibility of creating hot spots. This paper examined relative cost-effectiveness and assurance of achieving desired air quality associated with the four different traditional command-and-control (CAC) policy represented by uniform percentage reductions of emissions across all stationary sources, localized marketable permit system (LMPS), uniform marketable permit system (UMPS), and ambient permit system (APS) with a simple ROG dispersion relationship based on distances between stationary sources and receptors.

2. THE ECONOMICS OF ROG EMISSION CONTROL.

The net benefit of ROG emission control would be maximized at the optimal control level. The optimization problem can be defined as finding the set of $x_j$s which maximize:

$$1) \quad \max_{X_j} \sum_{i=1}^{n} \sum_{j=1}^{m} B_{ij}(X_j^{Optimal}) - \sum_{j=1}^{m} C_j(X_j^{Optimal})$$

where,

- $B_{ij}$: benefits of $i$th receptor due to emission controls from $j$th source, $i=1...n$, receptors, $j=1...m$, emission sources.

- $C_j$: total control costs of $j$th source.

- $X_j^{Optimal}$: optimal control level from $j$th source.

Assuming that second-order conditions are well behaved, the first order conditions (FOCs) for this optimization problem are:
This formulation works only if there is a linear relationship between sources and receptors. If there is a non-linear relationship between them, the transfer coefficient ($a_{ij}$) is no longer a constant and the problem would be more complicated.

The social optimum will be achieved if marginal control costs of the $j$th source equal the sum of $n$ receptors' marginal benefit due to emission controls on the $j$th source. The resulting optimal level of control for the $j$th source is $X_{j}^{Optimal}$. In practice, this social optimum is very difficult to identify, because estimating the benefit functions for all the receptors is difficult.

**Ambient Least-cost Strategy (APS)**

Current policy approaches to controlling air emission focus on alternative policies for achieving a given air quality goal. One such policy is to minimize the costs of achieving a certain ambient air quality standard. The problem can be formulated as:

\[
\begin{align*}
3) \quad & \text{Min } \sum_{j=1}^{m} C_{j}(X_{j}^{\text{Ambient}}) \\
& \text{st. } \sum_{j=1}^{m} a_{ij} X_{j}^{\text{Ambient}} \geq E_{i}
\end{align*}
\]

where,

- $a_{ij}$: the linear transfer coefficient that relates emission reductions from the $j$th source to air quality at the $i$th receptor.
- $E_{i}$: the emission reduction required to achieve the air quality standard at the $i$th receptor.
- $X_{j}^{\text{Ambient}}$: the number of tons of emissions to be removed under ambient strategy from $j$th source.

---

3 This formulation works only if there is a linear relationship between sources and receptors. If there is non-linear relationship between them, the transfer coefficient ($a_{ij}$) is no longer a constant and the problem would be more complicated.
This is equivalent to minimizing the following Lagrangian:

4) \[
\text{Min } \sum_{j=1}^{m} C_j(X_j^{\text{Ambient}}) + \sum_{i=1}^{n} \mu_i \left( \sum_{i=1}^{m} (E_i - a_{ij} X_j^{\text{Ambient}}) \right)
\]

where,

\( \mu_i \) : Lagrangian multipliers.

The FOCs for this problem are:

5) \[
c_j'(X_j^{\text{Ambient}}) = \sum_{i=1}^{n} \mu_i a_{ij}, \quad j=1,...,m
\]

The equation above shows that the marginal control cost for the \( j^{\text{th}} \) source \( (C_j'(X_j^{\text{Ambient}})) \) should be equal to the sum of the transfer coefficients weighted by Lagrangian multipliers \( (\mu_i = dC/dE_i) \). Here, the Lagrangian multipliers reflect the changes in total control costs due to changes in the ambient air quality control level at site \( i \). The total control costs of meeting ambient air quality constraints would be minimized if each source controls such that its marginal control cost is equal to its contribution to the total control costs of meeting the ambient air quality control levels. An ambient least-cost strategy will achieve the social optimum if:

6) \[
\sum_{i=1}^{n} B_j'(X_j^{\text{Optimal}}) = C_j'(X_j^{\text{Ambient}}) = \sum_{i=1}^{n} \mu_i a_{ij}, \quad \text{all } j=1,...,m
\]

That is, if the \( E_i \) are set optimally, and if the transfer coefficient approach is correct, then this method will achieve the social optimum. If equation 6) does not hold, the ambient least-cost strategy will not achieve the socially optimal level of control. However, it still minimizes control costs for society to meet the given ambient standards. The implementation of this system requires
that transfer coefficients \((a_{ij})\) be identified, which is very difficult and costly. In many air quality control regions, such as the San Joaquin Valley, transfer coefficients are unavailable.

**Emission Least-cost strategy (UMPS)**

An emission least-cost strategy does not require information about the transfer coefficients. It minimizes the total control costs of emission reductions, but it does not necessarily meet the ambient standard at all receptors. This system can be represented as:

\[
7) \text{Min } \sum_{j=1}^{m} C_j(X_j^{\text{Emission}}) \\
\text{st. } \sum_{j=1}^{m} X_j^{\text{Emission}} \geq E, \ j=1,\ldots,m
\]

where,

\(X_j^{\text{Emission}}\) : the emission reductions from \(j^{th}\) source.

\(E\) : total emission reduction from all sources needed to achieve the ozone standard.

This is equivalent to minimizing the following Lagrangian:

\[
9) \sum_{j=1}^{m} C_j(X_j^{\text{Emission}}) + \mu (E - \sum_{j=1}^{m} X_j^{\text{Emission}}), \ j=1,\ldots,m
\]

From the FOC, the solution satisfies:

\[
10) C_j(X_j^{\text{Emission}}) = \mu
\]

It can minimize the total control costs of achieving ambient standards if:
\[ 11) \sum_{j=1}^{n} \mu \alpha_j = C'_j(X_j^{Ambient}) = C'_j(X_j^{Emission}) = \mu, \ j=1,...,m \]

It means that the marginal effect of one more unit of emissions is the same on all receptors, regardless of where that unit is produced. If these conditions do not hold, as is the usual case, then the emission strategy does not meet the ambient standard at all receptors and hot spot problems occur.

Neither APS nor UMPS may not be an appropriate emission control policy for the San Joaquin Valley. The Valley has not yet identified the transfer coefficients necessary for APS. UMPS can be implemented which minimizes the total control costs of emission reductions, but some receptors could experience ozone concentrations that are higher than a required air quality standard in the Valley.

**Local Emission Least-cost Strategy (LMPS)**

Localized marketable permit system would be more appropriate to ensure that no receptors violate a required air quality and yet will require lower compliance costs than CAC approach. The stationary sources in each local area are considered to contribute equally to the air quality in the Valley. LMPS can be represented as:

\[
\text{Minimize } \sum_{r=1}^{8} \sum_{k=1}^{M_r} C_k^r(X_k^{rLocal}) \\
\text{st. } \sum_{k=1}^{M_r} X_k^r \leq E_r, \ r=1,...,8
\]

where,

\( C_k^r \): total emission control cost for \( k^{th} \) source in \( r^{th} \) local area, \( k = 1..m, \ r = 1..8 \).
$X_{k}^{\text{Local}}$: the tons of ROG emission to be removed in $r^{th}$ region by the $k^{th}$ source under LMPS.

$M_r$: number of sources in area $r$.

$E_r$: the total tons of ROG emission to be removed in area $r$.

The objective of this system is to minimize the total control costs to the stationary sources on the condition that the total ROG emissions for each local area ($r, r=1,\ldots,8$) is reduced to the level ($E_r$) that is necessary to attain a proposed air quality in that area. Unlike CAC, the stationary sources in each area are allowed to trade freely their emission permits. Sources with higher control costs buy emission permits from sources with lower control costs; thus, total control cost to the stationary sources to reduce ROG emissions is smaller than it would be without such trading of emission permits.

3. THE CASE STUDY: THE SAN JOAQUIN VALLEY OF CALIFORNIA

The San Joaquin Valley of California consists of eight counties and is approximately 350 miles in length and 50 miles in width. About 3.5 million people live in this Valley with a climate of hot summers and rainy winters. The Valley is a major agricultural production region and is also the second worst air quality region in California. Air quality in most of the counties in the San Joaquin Valley is much worse than the current ambient air quality standards. For each day, over 600 tons of ROG are emitted into the air in the Valley (CARB, 1993). Seventy percent of ROG emissions is from stationary sources. The other thirty percent of ROG emissions comes from mobile sources. The major stationary sources of ROG in the San Joaquin Valley are the petroleum refining and distribution industry. Table 1 details the stationary sources and their ROG emission
per day.

Table 1
Stationary Emission Inventory in the San Joaquin Valley.
(California Air Resource Board (CARB), 1993)

<table>
<thead>
<tr>
<th>Major Source Category</th>
<th>ROG Emissions (Tons/Day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Combustion</td>
<td>14 (4.0%)</td>
</tr>
<tr>
<td>Waste Burning</td>
<td>23 (6.6%)</td>
</tr>
<tr>
<td>Solvent Use</td>
<td>87 (24.9%)</td>
</tr>
<tr>
<td>Petroleum Process, Storage, and Transfer</td>
<td>140 (40.0%)</td>
</tr>
<tr>
<td>Industrial Process</td>
<td>12 (3.4%)</td>
</tr>
<tr>
<td>Misc Processes</td>
<td>82 (23.4%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>350 (100%)</strong></td>
</tr>
</tbody>
</table>

In the San Joaquin Valley, the stationary sources are clustered into a few cities within which emissions can be considered to have the same impact on the air quality. Kern and Fresno counties alone comprise 85% of ROG emissions stationary sources in the Valley. Table 2 details the distribution of ROG emitting stationary sources among eight counties in the San Joaquin Valley. Of the hundreds of plants in the Valley, 97 large plants with 250 sources account for more than 95% of the total ROG emissions. The 97 ROG emitting plants are analyzed in this study to illustrate the costs of controlling ROG emissions in the San Joaquin Valley.

The air quality in San Joaquin Valley is reasonably independent from pollution sources in the San Francisco areas because wind blows from the San Francisco bay to Sacramento Valley.
and then to Nevada. It is also protected from pollution sources in the Los Angeles areas due to the Tehachapi mountains that blocks emission from flying over to the San Joaquin Valley. Therefore, local stationary and mobile sources are responsible for the air quality in the Valley.

Table 2

Distribution of Stationary Sources in the San Joaquin Valley (CARB, 1992a)

<table>
<thead>
<tr>
<th>County</th>
<th>Number of ROG Stationary Sources</th>
<th>Percentage Share of Total ROG Emission in SJV</th>
<th>Major cities in which stationary sources locate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kern</td>
<td>169</td>
<td>80%</td>
<td>Bakersfield</td>
</tr>
<tr>
<td>Fresno</td>
<td>24</td>
<td>5%</td>
<td>Fresno</td>
</tr>
<tr>
<td>San Joaquin</td>
<td>25</td>
<td>3%</td>
<td>Stockton</td>
</tr>
<tr>
<td>Stanislaus</td>
<td>12</td>
<td>2%</td>
<td>Modesto</td>
</tr>
<tr>
<td>Merced</td>
<td>6</td>
<td>2%</td>
<td>Merced</td>
</tr>
<tr>
<td>Madera</td>
<td>3</td>
<td>5%</td>
<td>Madera</td>
</tr>
<tr>
<td>Tulare</td>
<td>3</td>
<td>3%</td>
<td>Tulare</td>
</tr>
<tr>
<td>Kings</td>
<td>8</td>
<td>0.3%</td>
<td>Hanford</td>
</tr>
</tbody>
</table>

Control Cost Data

Two general approaches for controlling further emissions from stationary sources are based on the smokestack emission control technologies. One approach requires the installation of secondary control equipment, which is comparable to existing equipment. This approach could reduce further emissions as long as secondary control equipment provides additional emission reductions; however, it would be expensive to employ additional control equipment to reduce
emissions further since a large part of the control cost is capital and installation cost. The other approach achieves a reduction in ROG emissions by increasing the destruction efficiencies of existing control equipment. The advantage of this approach is that it would be cheaper than the former because it only increases operating costs. However, the benefit to be realized by this approach is limited because most sources operate their control equipment near their maximum efficiencies (CARB, 1991a).

Observing the methods used by other studies, this study assumes that pollution control treatments can be applied in sequence when developing ROG emission control costs. For example, an incinerator of any size could control inlet gases with a maximum efficiency of approximately 90% (Vaart, Vatavuk, and Wehe, 1991). If we need to control additional emissions, we can sequentially install additional incinerators to control outlet gases from the initial incinerator. If an incineration methods with a 90% efficiency is applied initially, and one additional incinerator with same efficiency is applied again, then the incinerators will collectively yield a 99% (90% + 0.1*0.90%) control level. Therefore, the marginal control cost of achieving an additional 9% control is measured by the cost of an additional incinerator (Kim, 1994). Developing emission control cost functions for each source requires the data for ROG emission from stationary sources, types of control devices in place on the sources, their control efficiencies, and the costs of installing and operating the equipment. Information about stationary sources and their emissions was obtained from the California Air Resource Board’s Emission Data System (CARB, 1992a, 1992b), while the types of control measures employed by the stationary sources measures and their costs were provided by the San Joaquin Valley Unified Air Pollution Control District(SJVUAPCD, 1991).
It is, however, difficult to measure accurately the cost of controlling amounts exceeding current levels unless plants identify their choices of alternative methods with their corresponding control costs. Because of this estimating additional control costs is likely to carry with it a wide margin of variability.

**ROG Emission Control Scenarios**

In this study, four different ROG emission control policies are analyzed in the San Joaquin Valley: 1) Command and Control (CAC) policy represented by uniform percentage reductions in emissions, 2) Uniform Marketable Permit System (UMPS) in which all stationary sources in the Valley freely trade their ROG emission permits by one-to-one basis, 3) Localized Marketable Permit System (LMPS) that allows one-to-one permits trading only for stationary sources locate within the same localized zone, 4) Ambient Permit System (APS) with a simple ROG emission dispersion relationship based on distances between stationary sources and receptors. Control costs associated with ROG emission reductions of 25%, 50%, 75%, 90% under the four different control policies were applied to stationary sources to estimate cost savings by marketable permit systems. The current control system, however, uses emission trading in a limited way and thus is more cost-effective than CAC policy. The cost savings indicated in this study represent the differences between the costs of the marketable permit systems and those of CAC. Thus, they overstate the advantages of the marketable permit systems relative to the current policy.
**Emission Diffusion Relationship**

The implementation of APS requires an air quality model to identify sources’ emission diffusion relationships to each receptor’s air quality. In many air quality control regions, such as the San Joaquin Valley, air quality models are not available because of their complexity and costs associated with them. In this study, to provide an empirical comparison among different marketable permit systems, a simple linear emission dispersion relationships for ROG is assumed. Contribution of an emission source to a receptor’s air quality is determined by the distance between the two. Because stationary sources in a county are concentrated in a major city, which is also the major receptor of that county, I calculated the linear emission transfer coefficients (a$_{ij}$)$^{4}$ among the major cities to represent emission dispersion relationships among counties in the Valley. However, the linear transfer coefficients assumed in this study is not an accurate presentation of actual ROG emission dispersion characteristics. The simple dispersion relationships are applied to this study to provide an empirical comparison of relative cost-effectiveness and assurance of air quality attainment between UMPS and LMPS. The control costs for APS in this study should not be considered as an accurate estimation of the actual least cost of achieving a required air quality in the Valley. Table 3 details the emission transfer coefficients among counties(cities).

\[ a_{ij} = 1 - \frac{d_{ij}}{d_{yv}} \]

where,
- $d_{ij}$: linear transfer coefficient from source i to receptor j.
- $d_{ij}$: distance between source i to receptor j in miles.
- $d_{yv}$: San Joaquin Valley in length (350 miles).
Table 3
The Emission Transfer Coefficients among Counties (Cities)

<table>
<thead>
<tr>
<th>County</th>
<th>Kern</th>
<th>Fresno</th>
<th>San Joaquin</th>
<th>Stanislaus</th>
<th>Merced</th>
<th>Madera</th>
<th>Tulare</th>
<th>Kings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kern</td>
<td>1</td>
<td>0.55</td>
<td>0.1</td>
<td>0.2</td>
<td>0.35</td>
<td>0.475</td>
<td>0.75</td>
<td>0.7</td>
</tr>
<tr>
<td>Fresno</td>
<td>0.55</td>
<td>1</td>
<td>0.5</td>
<td>0.625</td>
<td>0.775</td>
<td>0.9</td>
<td>0.825</td>
<td>0.85</td>
</tr>
<tr>
<td>San Joaquin</td>
<td>0.1</td>
<td>0.5</td>
<td>1</td>
<td>0.875</td>
<td>0.725</td>
<td>0.575</td>
<td>0.325</td>
<td>0.375</td>
</tr>
<tr>
<td>Stanislaus</td>
<td>0.2</td>
<td>0.625</td>
<td>0.875</td>
<td>1</td>
<td>0.85</td>
<td>0.725</td>
<td>0.45</td>
<td>0.475</td>
</tr>
<tr>
<td>Merced</td>
<td>0.35</td>
<td>0.775</td>
<td>0.725</td>
<td>0.85</td>
<td>1</td>
<td>0.85</td>
<td>0.575</td>
<td>0.6</td>
</tr>
<tr>
<td>Madera</td>
<td>0.475</td>
<td>0.9</td>
<td>0.575</td>
<td>0.725</td>
<td>0.85</td>
<td>1</td>
<td>0.725</td>
<td>0.75</td>
</tr>
<tr>
<td>Tulare</td>
<td>0.75</td>
<td>0.825</td>
<td>0.325</td>
<td>0.45</td>
<td>0.575</td>
<td>0.725</td>
<td>1</td>
<td>0.95</td>
</tr>
<tr>
<td>Kings</td>
<td>0.7</td>
<td>0.85</td>
<td>0.375</td>
<td>0.475</td>
<td>0.6</td>
<td>0.75</td>
<td>0.95</td>
<td>1</td>
</tr>
</tbody>
</table>

4. EMPIRICAL RESULTS

The emission control costs increases at the increasing rate as percentage of ROG emission reductions become greater, which reflects that controlling further emissions becomes more difficult and costly. Table 4 details the emission control costs associated with the four different emission control policies in the San Joaquin Valley.

In the Valley, the major stationary sources emitting ROG are those involved in petroleum processing, storage, and transfer, and the control costs for controlling ROG in this industry are lower than other industries (Kim, 1994). The total emission control costs associated with the CAC policy represent the highest costs of ROG emission reductions because it excludes any possibility of trading of emission permits. Under CAC policy, the costs of controlling emissions by county are not always directly proportional to the volume of emissions produced within that county. For example, Kern county incurs 60% of the total ROG control costs which is relatively
low when one considers the actual volume of its ROG emissions, which is 80% of total ROG emissions in the San Joaquin Valley. The primary sources of Kern county’s emissions are engaged in petroleum, processing, storage, and transfer, which enjoy lower emission control costs. Conversely, Fresno county, which is responsible for only 5% of the total ROG emissions in the Valley, incurs 20% of the total ROG emission control costs. Its share of the total ROG control cost is disproportionate high because the ROG is produced primarily by sanitary landfill and waste management (CARB, 1992a).

Table 4

<table>
<thead>
<tr>
<th>ROG Emission Control Policies</th>
<th>ROG Emission Controls in Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>CAC</td>
<td>$6.81</td>
</tr>
<tr>
<td>UMPS</td>
<td>$4.18</td>
</tr>
<tr>
<td>LMPS</td>
<td>$4.26</td>
</tr>
<tr>
<td>APS</td>
<td>$4.16</td>
</tr>
</tbody>
</table>

The shares of the total control costs for other counties are proportional to their contribution to the total emission in the San Joaquin Valley. Table 5 details the distribution of emission control costs for each county in the San Joaquin valley. Under CAC, the percentage share of the total control costs for each county is constant over the range of ROG emission reductions considered in this study.

The cost of controlling ROG emissions through the use of market incentive-based systems are much lower than CAC. The cost savings stem from the fact that each stationary sources are
allowed to trade their emission permits. The total control costs of meeting ROG emission reductions to achieve a required air quality in the Valley is minimized by allowing each source to trade their permits according to their differentiated contribution to the receptors’ air quality. The APS with a simple emission dispersion characteristics in this study shows that a

Table 5

The Distribution of ROG Emission Control Costs among Counties (in Percentage)

<table>
<thead>
<tr>
<th>County</th>
<th>25% ROG Emission Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CAC</td>
</tr>
<tr>
<td>Kern</td>
<td>60.83%</td>
</tr>
<tr>
<td>Fresno</td>
<td>25.13%</td>
</tr>
<tr>
<td>San Joaquin</td>
<td>6.79%</td>
</tr>
<tr>
<td>Stanislaus</td>
<td>1.65%</td>
</tr>
<tr>
<td>Merced</td>
<td>0.62%</td>
</tr>
<tr>
<td>Madera</td>
<td>3.51%</td>
</tr>
<tr>
<td>Tulare</td>
<td>0.58%</td>
</tr>
<tr>
<td>Kings</td>
<td>0.90%</td>
</tr>
</tbody>
</table>

significant cost saving from CAC policy. Unlike CAC policy, the share of the total control costs for each county under the APS varies with the emission control level. The counties with more permit trading possibilities reduce their share of the total control costs by trading permits. In particular, Fresno county significantly reduces its share to the total control costs at the 25% emission reduction level by almost 10% through buying emission permits from sources in Kern county. However, as higher emission reductions are imposed on the stationary sources and the possibility of trading permits is reduced, proportionally smaller cost savings are generated by
applying APS to the San Joaquin Valley.

UMPS minimizes the total control costs of ROG emission reduction in the San Joaquin Valley, but it does not necessarily guarantee that all receptors meet a required air quality. Since UMPS does not consider each sources different contribution to the same receptors, hot spots can be created by one-to-one permit trading among them. If UMPS is applied to a wide region where sources are widely distributed, hot spots can be easily created and their problems might be serious. In the San Joaquin Valley, although stationary sources are clustered in a few major cities, they still be engaged in trading of their permits across cities with long distances. Under UMPS, hot spots are created in San Joaquin, Fresno, Stanislaus, Madera, and Merced counties. Because San Joaquin county locates further away from other counties in the Valley and its sources have relatively higher emission control cost, the county experiences more serious hot spot problems than other counties as a result of buying more permits based on one-to-one trading. Table 6 displays hot spots created with the simple ROG emission dispersion relationship assumed in this study.

LMPS divided the San Joaquin Valley into eight local areas by county. The stationary sources in each area are considered to contribute equally to the air quality in the Valley. The objective of this system is to minimize the total control costs to the stationary sources on the condition that the total ROG emissions for each local area is reduced to the level that is necessary to attain a required air quality in that area. The stationary sources in each area are allowed to trade freely their emission permits. The total control cost to the stationary sources to reduce ROG is smaller than it would be without such trading of emission permits. Stationary sources are densely clustered in Kern county, which is responsible for 80% of the ROG emissions in the
Valley. LMPS can result in significant cost savings if stationary sources in Kern county are allowed to freely trade their emission permits. Conversely, counties such as Madera, Merced, and Kings will not realize significant cost savings if LMPS is instituted because they have few stationary sources. LMPS applied to the San Joaquin Valley shows that the total control cost is slightly higher than the least-cost strategy, APS and also prevent hot spots from being created.

### Table 6

**The Resulting ROG Emission Reductions (in %) in Each County with UMPS**

<table>
<thead>
<tr>
<th>County</th>
<th>ROG Emission Controls in Each County (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25% Reduction</td>
</tr>
<tr>
<td>Kern</td>
<td>26.0%</td>
</tr>
<tr>
<td>Fresno</td>
<td>25.1%</td>
</tr>
<tr>
<td>San Joaquin</td>
<td><strong>22.9%</strong></td>
</tr>
<tr>
<td>Stanislaus</td>
<td><strong>24.1%</strong></td>
</tr>
<tr>
<td>Merced</td>
<td><strong>24.6%</strong></td>
</tr>
<tr>
<td>Madera</td>
<td>25.0%</td>
</tr>
<tr>
<td>Tulare</td>
<td>25.5%</td>
</tr>
<tr>
<td>Kings</td>
<td>25.4%</td>
</tr>
</tbody>
</table>

### 5. CONCLUSION

This study analyzed the ROG control costs of stationary sources in the San Joaquin Valley of California. Marketable permit system are more cost-effective in meeting a required air quality standard than CAC in the Valley. UMPS minimizes the control cost to reduce the total ROG emission, but some counties could experience air quality worse than other counties if one-to-one
permits trading is allowed. LMPS would be more appropriate to ensure that no counties violate a required air quality and yet will require lower compliance costs than CAC approaches. In fact, LMPS can achieve a desired air quality standards as a low cost close to the least-cost strategy in the San Joaquin Valley.

Despite our best efforts, the ROG emission control costs estimated in this study are subjected to many uncertainties and measurement errors. First, the cost functions of emission controls from stationary sources used in this study have some weaknesses. It is assumed that stationary sources apply the same control measures to reduce emission further. Alternatively, sources could use cleaner fuels, change production processes, or install new control equipment with higher control efficiencies, rather than installing the same device in sequence. This study does not allow for these possible choices; thus we probably overestimate control costs for ROG emission reductions. Second, the simple ROG emission dispersion relationship employed in this study does not represent the actual emission diffusion characteristics in the San Joaquin Valley. The control costs for APS is not an accurate estimation of the least cost of achieving a required air quality in the San Joaquin Valley. Finally, this study focus only on ROG emitting stationary sources. If mobile sources were to included and allowed to trade emission permits across stationary and mobile sources, this would results in further cost savings of emission control. This study is likely to overestimate the true control costs because most factors provide upward bias to control cost; however, the magnitude of overestimation cannot be measured accurately.
References


Kim, Hong Jin, “The Economic Impact of Ozone Regulations in the San Joaquin Valley of California,” unpublished Ph.D. dissertation, Department of Agricultural Economics, University of California at Davis, 1994


