How Effective Are Appeals for Cooperation and Pecuniary Incentives at Reducing Car Trips? A Case Study of the Spare the Air Program

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ABSTRACT: This paper measures the effectiveness of a pollution control program in the San Francisco Bay Area that relies on pecuniary incentives and self-restraint to reduce car trips on summer days forecast to exceed federally-imposed air pollution limits. Survey data and public transit ridership data have previously been used to measure the effectiveness of the "Spare the Air" (STA) program, but they are believed to provide biased estimates of reduced car trips. This paper is the first to use data on actual Bay Area traffic volumes to estimate the extent to which the pollution-control program reduces car trips. Using two distinct sets of data on traffic volume and several estimation procedures, our results show significant effects of the STA program in only one estimation procedure and suggest previous estimates of the effectiveness of STA are overstated. The data permit separate estimation of the effect of appeals for cooperation and the effect of pecuniary incentives. The "cooperation effect" is found not to be statistically significant in most estimation procedures and is found to increase traffic volumes where it is significant. These findings are related to a literature that examines the extent to which appeals for cooperation can ration supply where prices do not.

1. INTRODUCTION

The San Francisco Bay Area Spare the Air (STA) program is intended to reduce air pollution on particularly smoggy days to keep air quality from falling below health-based standards imposed by the state of California and the U.S. Environmental Protection Agency. Historically, the program has consisted of public appeals to motorists to reduce the number of car trips they make by either using alternative means of transportation, such as public transportation, or eliminating trips. In more recent years, the program has supplemented appeals for self restraint with free rides on many public transit networks throughout the nine-county Bay Area, including the Bay Area Rapid Transit (BART) subway system. In essentially urging motorists to conserve clean air, the program is similar to appeals for conservation of energy, vaccines, and other public goods, all of which contribute to a growing literature on the effectiveness of cooperation amid supply shortages.

Appeals for conservation are used to alleviate shortages in circumstances in which prices do not or cannot adjust to market forces. Were prices free to adjust, they would act as an efficient rationing mechanism. Where prices cannot adjust, alternative rationing devices are needed. During the oil panics of the early 1970s, for instance, prices were fixed and willingness to wait in line at gas stations became the primary rationing device. Coercive screening can also be used to distribute scarce commodities to preferred groups, though it is often politically untenable. In circumstances when the price mechanism does not function properly, cooperation—or self-restraint—can theoretically be used to allocate scarce resources in a socially beneficial way. The extent to which such appeals are effective is an empirical question that we address herein. It has also been considered in a variety of other contexts and is of great salience amid heightened environmental concern and increasing scarcity of traditional energy resources.

This paper proceeds with a review of the literature on appeals for cooperation in Section 2. Section 3 provides background information about the STA program and reviews previous studies of the effectiveness of STA. Section 4 presents the data and Section 5 introduces the econometric model. Results are presented in Section 6, which is followed by discussion and conclusions in sections 7 and 8, respectively.

2. APPEALS FOR COOPERATION AS A MECHANISM TO RATION SCARCE RESOURCES

STA can be effective if it either sufficiently raises the opportunity cost of car trips (by making public transit cheaper) to induce substitution to other modes of transit, or if it persuades individuals to deviate from self-interested utility maximization by eliminating trips or abandoning their preferred method of travel. Because the benefits of conservation are not fully internalized by those who exhibit self-restraint, conservation is expected to be underprovided and subject to free rider problems, unless consumers exhibit altruism. Appeals for cooperation are likely to fail in instances where there is anonymity and no mechanism to punish free riders (cheaters) such as in a one-shot game. There is, however, evidence of cooperation, which can be explained by a need for social acceptance, a desire to protect social norms, and demand for self-approval (De Janvry, Sadoulet and Villas-Boas 2006).

Other attempts have been made to measure the effectiveness of calls for cooperation. Much of the early work in this regard surrounds energy conservation during the energy crisis induced by the Arab oil embargo of 1974. Peck and Doering (1976) found little change in household home gas demand that could not be explained by prices. Liquid petroleum users, who faced considerable increases in gas prices and calls for conservation, significantly increased their energy efficiency. Natural gas users, who were also encouraged to conserve energy but who did not face price increases, did not improve energy efficiency. The authors thusly concluded that cooperation was not important in energy demand reductions. Mayer (1977), however, found a ten percent decrease in home heating gas and electricity consumption in New Jersey during winter 1974 and principally attributed the reduction to cooperation and changing social norms.

Taylor and Blattenberger (1979) used annual electricity demand observations to forecast energy demand during the energy crisis of 1974 and 1975. By comparing the difference in forecasts and observed demand for 48 contiguous states, they found 29 states reduced demand relative to the forecasts in 1975, whereas only 2 did in 1974 (pre-crisis). These differences, the authors contended, are not explained by prices.

More recently, crisis-induced appeals for energy conservation have been in response to supply shortfalls on electricity grids. Such shortfalls can be in response to high demand on very hot or cold days (when household electricity use peaks) or failures along the grid, such as a power plant going offline unexpectedly. In California, these appeals are common on hot summer days and consumers are urged to “flex your power” through alerts issued by the state utility commission. Consumers are warned that failure to reduce demand can result in rolling power outages, as regulators force demand reductions to protect the grid. Individual-level and even city- and region-level electricity demand is not recorded by day. This has hindered analysis of cooperation in these circumstances. Reiss and White (2003), however, investigated the extended effect of a conservation campaign during the California energy crisis of 2000-01. They found that following appeals for conservation, households reduced energy consumption for an extended period of time by 6%, absent any economic rationale to do so.

Appeals for conservation are also made following natural disasters such as storms, fires and earthquakes. Appeals for water conservation are common during droughts and floods when safe water is in short supply. The effectiveness of appeals for water conservation has been analyzed in the literature. Renwick and Archibald (1998) and Michelson, McGuckin and Stumpf (1998) provide surveys of non-price demand management. Appeals for energy conservation followed Hurricane Katrina, which disrupted U.S. oil refining capacity in 2005. Cooperation was urged following the 2008 earthquake in China when tents badly needed in earthquake-stricken areas were being purchased by consumers in non-impacted areas who feared aftershocks.

Conservation or self restraint has also been urged amid shortages of other commodities. De Janvry, Sadoulet and Villas-Boas (2006), for instance, exploited a natural experiment on the UC Berkeley campus that involved rationing of flu vaccines to the most susceptible demographic groups (namely the elderly and infirm) during the 2004 flu vaccine shortage in the U.S. They defined two treatments randomly assigned over the campus community. The first treatment group received a notice about a shortage of vaccines at upcoming vaccination clinics. The second treatment received the same notification and a call for self-restraint among non-priority populations. A control group consisted of the rest of the community that received no notifications. Based on survey data from the clinics, the authors observed the effect of the call for self restraint (conditional on receiving information about shortages) by examining the difference in demand among the two treatment groups. They found that provision of information about scarcity had the effect of increasing demand. The increase in demand was only partially offset by self-restraint. Demand increased 17% with the entire increase occurring among non-priority populations. The appeals for cooperation, therefore, failed to reduce demand and actually induced greater demand among the very segments of the population that were least at risk.

The present study contributes to this literature on cooperation by determining the extent to which motorists in the Bay Area heeded calls for "conservation" of clean air on particularly smoggy days. It identifies a pure cooperation effect as well as the responsiveness of commuters to changes in commute costs. Voluntary self-restraint is relevant as the public faces scarce energy supplies and grows increasingly concerned about environmental problems like global warming. Appeals for cooperation may be more politically feasible than other (coercive) methods of rationing scarce resources, so their effectiveness is important to policy.

3. SPARE THE AIR PROGRAM

Since establishing the Spare the Air (STA) program in 1991, the Bay Area Air Quality Management District (BAAQMD), a regional government authority responsible for maintaining safe air quality levels, has declared 190 STA days, during which Bay Area residents have been urged to reduce car trips, minimize use of polluting household products, like aerosol cleaners, and postpone use of gas-powered yard equipment. The STA days are declared when air quality forecasts suggest the Air Quality Index (AQI) in the Bay Area will exceed levels of safety required by state and federal law. The AQI translates concentrations of air pollutants—ozone, carbon moNOXide, nitrogen dioxide, sulfur dioxide, and particulate matter—into a number on a scale of 0 to 500, with cleaner air registering lower values on the AQI. Good air quality ranges from 0-50. Federal standards are exceeded when the AQI reaches past 100. Air quality above 100 poses a risk to sensitive groups, including active children, asthmatics and those with respiratory disease. These groups are encouraged to stay inside when the AQI exceeds 100. The

AQI in the Bay Area is generally exceeded in summer months when clear skies, calm winds, hot temperatures and temperature inversion trap air pollutants near the ground.

The BAAQMD issues STA alerts one day before air quality is forecast to exceed safe AQI levels. Bay Area newspapers, radio stations, and television networks publicize the STA alerts to the public, which can also register for email alerts from the air quality district. In addition, the air quality district operates a public awareness campaign to inform the public about the program. It includes print, radio and television advertisements, as well as advertisements on buses and trains. The combined efforts of the air quality district and the news media have succeeded in generating awareness about the STA program among 76% of the public, according to analysis by the air quality district. On any given STA day, 66% of the public is aware of the STA alert (BAAQMD 2005). The San Francisco Chronicle in 2006 declared STA “old hat by now” (SF Chronicle 2006a).

Before 2004, the STA program consisted exclusively of appeals for the public to reduce polluting activities, principally by eliminating car trips. Beginning in the middle of the 2004 STA season, the district began offering free public transit rides in cooperation with the Metropolitan Transportation Commission (MTC) and Bay Area public transit agencies. In 2004, participating agencies included the BART subway system and select regional bus lines and trans-bay ferries. Since 2004, the number of participating transit agencies increased from 21 to 29. A complete list of participating transit agencies is provided in Appendix A. Free transit rides have, during some STA seasons, been restricted to commute hours or morning hours. These restrictions are enumerated in Appendix A. Free transit rides are funded by the air quality district and the MTC and cost on average $2.5 million per day to reimburse transit agencies. In 2006, more than $14 million was spent on STA days by mid-summer. When annual funding is exceeded, subsequent STA days do not include free transit rides. In addition, STA days declared on Saturdays and Sundays do not include free transit rides. Because some STA days include free transit rides and others do not, we are able to estimate both a “cooperation effect” and the effect of changes in commute costs. A list of STA days that includes free transit rides and those that do not is included in Appendix A.

Public transit ridership increases substantially on Spare the Air days, prompting the air quality district, the MTC, and the media to claim the STA program as a success. BART ridership increased 5-10% (16,000-33,000) on STA days in 2006. Demand for a cross-bay ferry from Sausalito to San Francisco increased 510% to 12,000 passengers on July 21, a STA free-fare day. In September 2004, the BAAQMD reported “great response” to the STA alerts earlier that summer, citing survey results that 7% of 5 million drivers reduced car trips because of STA. On the second and final STA day of 2007, the MTC reported increased ridership for key transit agencies based on comparisons with ridership data from one week before the STA day: San Francisco's Muni, 41%; AC Transit, 27%; Tri Delta Transit, 41%; BART, 1%t; Vallejo Ferry, 27%; and the Golden Gate Ferry's Sausalito-to-San Francisco runs, 289%.

Jumps in transit ridership have been used by air quality officials and transit authorities to claim the STA program is a success. However, such figures do not reveal the extent to which the STA has reduced air pollution or even the extent to which appeals for motorists to reduce car trips are heeded. Public transit ridership increases on free fare STA days can be expected to overstate the number of reduced car trips because the increases may reflect substitution toward transit from other non-polluting modes of transportation such as walking or biking. In addition, free fares may induce additional trips that would not have been made absent the free fares. The substantial increases on ferries, for instance, may reflect demand from tourists and other “joy riders.” As the San Francisco Chronicle reported in 2006 following a STA day, it is “clear…(Bay Area residents) are going anywhere but work” and that they have “earned some humorless weekday commuters' ire for the enthusiasm with which they've been packing trains, buses and ferries" (SF Chronicle 2006b). BART has estimated a 75% increase in leisure travel on STA days.

The BAAQMD has also commissioned several surveys to more accurately determine the effectiveness of the STA program. A 2005 analysis based on 315 15-minute telephone surveys of Bay Area drivers estimated that 7.3% of Bay Area drivers eliminated at least one car trip because of STA. This figured matched that of 2004, which the report calls a "remarkably successful" campaign (BAAQMD 2005). The report estimated the campaign persuaded 345,299 drivers to reduce their driving by a total of 2,173,176 miles. Considering both driving and product-use reductions, the campaign is estimated to have reduced emission of an estimated 1.5 tons of nitrogen oxides (NOX), 1.7 tons of reactive organic gases (ROG), and 0.5 tons of particulate matter (PM10) per STA day.

There is reason to suspect this analysis may also present biased estimates of the STA effect. The survey was by random-digit dial, and, even with monitoring of demographic attributes, may produce biases, including non-response bias and response bias, including social desirability bias or "yeah-saying" (see for instance Hansen and Hurwitz 1946 and Hansen et al. 1951). In addition, despite care to disguise the true questions of interest to the interviewer, there is reason to believe the survey may suffer interviewer bias by which respondents provide socially desirable responses.

The interviews were conducted on the evening of an STA day. Amid a series of transportation-related questions, respondents were asked if they intentionally increased or decreased car trips on the day of the interview. Those who indicated they decreased car trips were asked why they reduced each trip. This questioning is likely to produce social-desirability bias (or yeah-saying), which would tend to overstate the number of trips reduced. Those respondents who recalled that the day of the interview was an STA day would infer that the socially desirable response is to reduce car trips. They would provide that answer in order to "please" the interviewer (Mitchell and Carson 1989; Kahneman and Knetsch 1992). The authors do not account for this potential bias, though they do recognize the potential for interviewer bias and propose this indirect questioning as a correction. The report also acknowledges the tendency for those who report reduced car trips to overstate the number of reduced trips. They, therefore apply a correction factor of 0.5. That is, those who reported two reduced car trips are assumed to have reduced one car trip. The report adopts this methodology from the California Air Resources Board but does not substantiate why it is appropriate in this context.

The STA program has been criticized for subsidizing public transit for regular transit riders in addition to regular motorists whose behavior it wishes to change on STA days. Scarce dollars for fighting air pollution can be spent in a number of ways. Therefore, programs have been compared on the basis of their cost effectiveness—measured as the cost per ton of emissions reductions. It is important, therefore, to determine the effectiveness of the STA program. Policy makers in San Francisco need to know if their air-pollution-reduction spending can be better directed to other programs (such as programs that pay drivers to retire old, polluting cars). Policy makers in other cities need to know if they should adopt programs like STA, as some have indicated they may. Given the need to properly evaluate the STA program within the portfolio of pollution-reducing policies, it is important to evaluate its impacts in an objective manner, free from the potential biases that have plagued prior attempts at evaluation.

4. DATA SOURCES AND DESCRIPTIVE STATISTICS

Whereas previous efforts to quantify the effect of the STA program are likely to suffer from biased estimates, this paper uses econometric methods and data on actual traffic volumes to more accurately measure the reduction in car trips due to STA. In this section we describe data sources and provide summary statistics.

A. Data Sources

Traffic Volumes--Two unique sets of traffic volume data were obtained. A first set of traffic volume data are from the Freeway Performance Management System (PeMS), a network of more than 7,000 roadway sensors that gather historical and real-time information on traffic flows throughout California. Operated by the California Department of Transportation (CalTrans) and the Department of Electrical Engineering and Computer Science at UC Berkeley, the system detects roadway traffic with loop detectors that operate like metal detectors buried one inch below the road surface. Each of the 7,000 detectors covers an entire expanse of roadway (all traffic lanes) and transmits information to computers via phone lines, fiber lines or wireless connections every 30 seconds.

We use this data set to develop a panel of 563,403 observations on traffic volume across 1,200 stations over summer months (May-September) from 2004 to 2006. Reliability of these data may be an issue due to sensor malfunction. In addition, outlier observations will occur due to extraordinary events such as road closures and accidents. Thus, we utilized two approaches to cleanse these data of questionable observations. First we dropped outlier observations that were identified as those with studentized residuals greater than 2.5 in absolute value. Specifically, we ran separate OLS regressions on each cross-section to calculate the studentized residuals. The studentized residual is defined as:

$$e_i^s = \left| \frac{e_i}{\sqrt{s_{(i)}^2 (1 - h_i)}} \right|,$$

where e_i is the residual for observation *i*, $s_{(i)}$ is the standard deviation with the ith observation deleted and h_i is the leverage statistic (Belsley et al. 1980). Observations with studentized residuals greater than 2.5 in absolute value were determined to be outliers and were deleted. Stations with fewer than 500 observations over the 20-month period were considered to be unreliable and were dropped. This produced an unbalanced panel that includes observations from across the Bay Area's CalTrans District 4. (A map of District 4 is included in Appendix B).

A second set of traffic-volume data was obtained from bridge counts on four Bay Area bridges: the San Francisoco-Oakland Bay Bridge (SFOBB), the Richmond-San Rafael bridge (Richmond), the Dumbarton bridge and the San Mateo bridge. Appendix B includes a map of these bridges. These data were collected by CalTrans and were obtained through a public-records-act request. These data were not collected until 2006, which limits our analysis to two summers of STA. They produce a panel of 1201 observations across 4 bridges over 10 months (May-September) from 2006-2007. As with PeMS data, observations with studentized residuals in excess of 2.5 in absolute value were dropped as outliers, producing an unbalanced panel. No more than 7 observations were dropped from any bridge and only 24 observations were dropped in total.

STA Days—The dates of those days declared STA days were obtained from the BAAQMD. The determination of which STA days included free fares on public transit was made by examining press releases from the BAAQMD, which has issued a press release for each STA day and indicated whether free transit rides are offered on the STA day since 2004, when BART first began offering free rides.

Temperature—Traffic volumes are impacted by weather conditions, with extreme weather inducing substitution away from public transit. Because hot weather is expected to induce greater demand for car trips and because STA days are correlated with hot weather, it is important to include temperature in equations that estimate the effect of STA. We use data from the National Oceanic and Atmospheric Administration on the daily high temperature in Livermore, Calif. to control for temperature effects. Because we limit our analysis to summer months, we can assume that moderate low temperatures will not significantly impact transportation decisions. Rather, summer transportation decisions in the Bay Area are likely impacted by only one climatic variable—hot weather. Bay Area climate is such that inland areas, like Livermore, experience greater temperature variation than coastal areas, which are moderated by proximity to the ocean. Therefore, we expect temperature to be of greater influence on transportation decisions in inland areas where summer highs typically exceed those of coastal areas like the city of San Francisco. Controlling for temperature with observations from Livermore eliminates potential omitted variable bias, as we discuss later.

Other data—Traffic volumes vary by day, month and year. In addition, state holidays are likely to impact traffic volumes. We control for these variables using fixed effects.

B. Descriptive Statistics

Figure 1 depicts the fluctuation in traffic volumes by day of the week. Friday has the highest average demand and Sunday the least. To control for the weekly cycle of traffic volumes, we include day of the week fixed effects in the subsequent regressions. We also control for seasonality by restricting our sample to summer observations and by including month fixed effects. As Figure 2 shows, traffic volumes rise toward the middle of the summer (July) and then decline. Figure 3 shows that annual traffic volumes rose through 2005 and have been declining since.

Figure 1: Mean Daily Traffic Volumes by Day of the Week

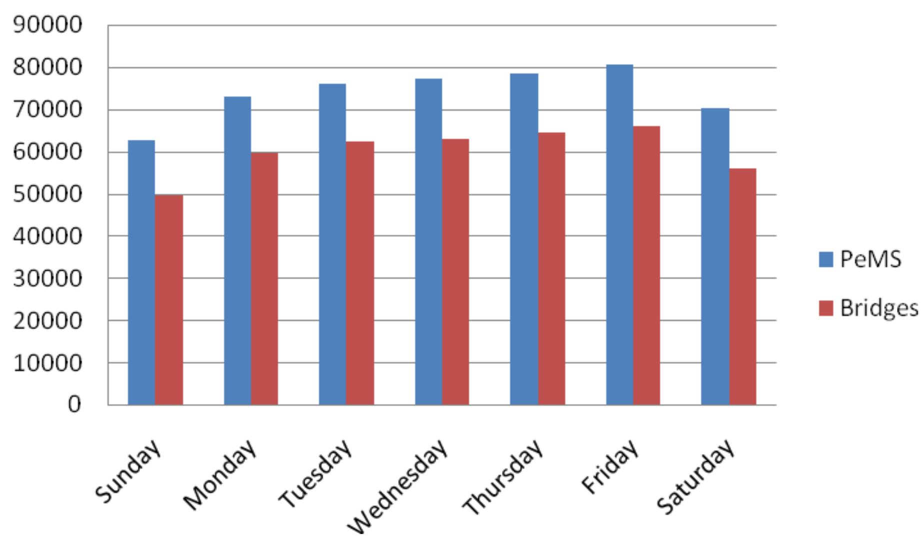

Figure 2: Mean Daily Traffic Volumes by Month

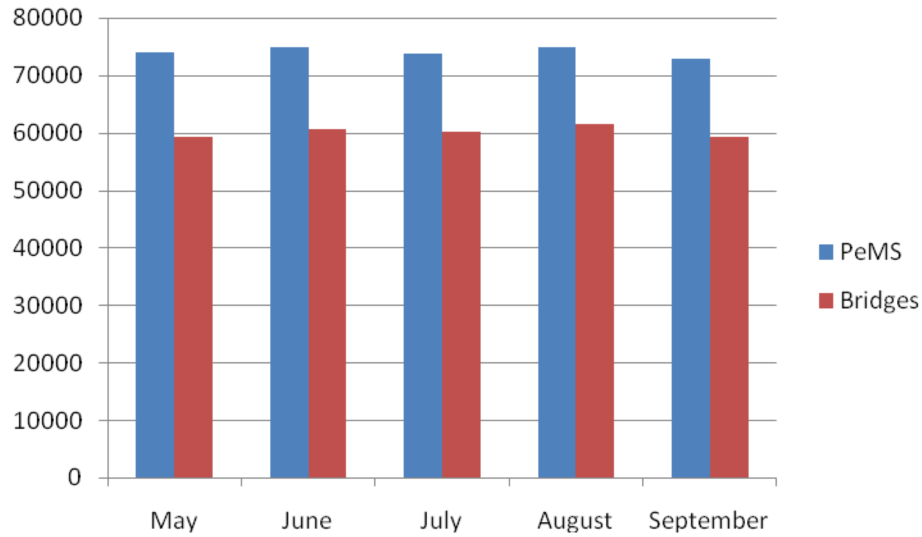

Figure 3: Mean Daily Traffic Volumes by Year

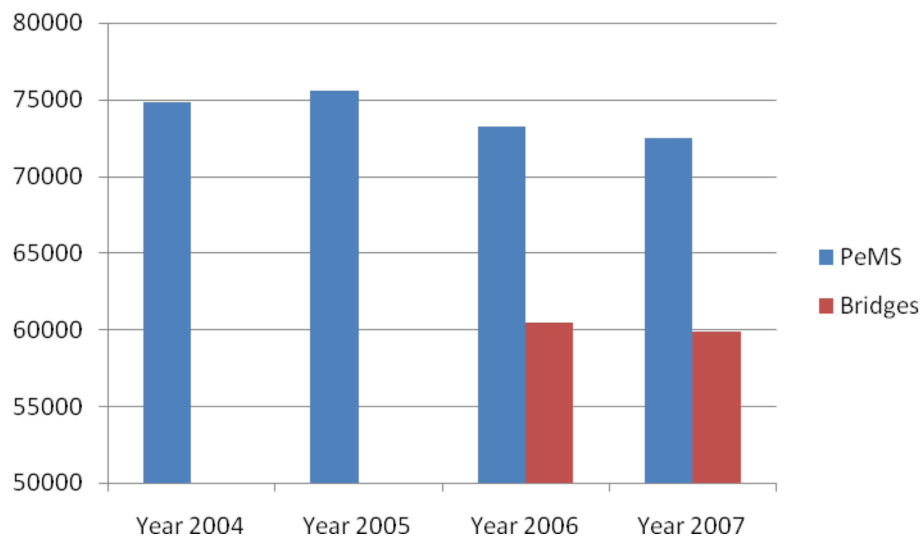

Table 1 reports summary statistics for traffic volume by bridge for the bridge data set and for the aggregated data from PeMS. Traffic volumes declined for all bridges in 2007 relative to 2006. PeMS data show a decline in traffic volume that began after 2005

Table 1: Summary Statistics

	2004	2005	2006	2007
Mean Daily PeMS Traffic Volume	74871.81	75548.03	73270.97	72489.69
Mean Temp	84.73314	85.04793	87.40214	84.38641
Max Temp	104	104	112	108
Min Temp	66	63	66	61
No. STA Days	3	1	11	2
No. Free STA Days	2	1	6	2
Mean Daily Dumbarton Bridge Traffic Volume	--	--	31303.17	30246.78
Mean Daily Richmond Bridge Traffic Volume	--	--	36027.85	2913.242
Mean Daily SFOBB Bridge Traffic Volume	--	--	126459.8	126848.3
Mean Daily San Mateo Bridge Traffic Volume	--	--	48045.22	46944.32

5. ECONOMETRIC MODEL

This section presents the econometric model used to estimate the effect of the STA program on traffic volumes in the Bay Area. We estimated the following equation using PeMS data:

$$TVit = \alpha_i + \beta_1 STA_t + \beta_2 STAFREE_t + \beta_3 TEMP_t + \beta_4 HOLIDAY + \sum_{j=1}^{6} \gamma_j DAY_j + \sum_{k=1}^{4} \phi_k MONTH_k + \sum_{l=1}^{3} \delta_l YEAR_l + \varepsilon_{it} \tag{1.0}$$

where *i* subscript denotes station, the cross-sectional level of observation; *t* denotes day, the longitudinal level of analysis; j = Sunday, Monday, Tuesday, Wednesday, Thursday, Saturday; k = May, June, July, August; and l = 2004, 2005, 2006. TV_{it} then represents the daily observed traffic volume at each station and α_i is a station-specific intercept. STA is a dummy variable equal to 1 if the date is an STA day and 0 otherwise. Similarly, STAFREE is equal to 1 if the STA day includes free transit fares and is equal to 0 otherwise. STAFREE, therefore, represents the marginal effect of free fares on traffic volumes. β_1 and β_2, the coefficients on STA and STAFREE, are coefficients of interest in the present analysis. β_1 represents the reduction in traffic volume due to STA program calls for trip reduction. Dividing β_1 by the mean traffic volume in the sample produces the percent reduction in traffic volume as a result of appeals for cooperation and is referred to as the "cooperation effect." β_2 represents the marginal impact of free transit rides, and, when divided by mean traffic volume in the sample, constitutes the percent reduction in traffic volume due to free fares on a STA day; it is called the "price effect." TEMP is a continuous variable measuring daily high temperatures in Livermore, California. DAY, MONTH, and YEAR are dummy variables used to control for day of the week, month and year effects, respectively.

With repeated observations over time, a fixed-effects model accounts for permanent station effects. Identification requires that there are no unobserved determinants of STA declarations that co-vary with traffic volumes. Temperature is thought to affect both STA day and traffic volumes and is included as a covariate in (1) and all other regression equations in this paper. We believe our identifying assumption holds once we control for temperature.

The effect of self-restraint in response to appeals for cooperation may be counteracted by other behavioral responses, as detailed by de Janvry, Sadoulet and Villas-Boas (2006). These include increased demand for the scarce commodity because of increased salience (amid appeals for conservation), decreased procrastination of consumption, and loss aversion. None of these effects is expected to be present in the current context because the scarce commodity—clean air—is really not scarce in any practical and immediate sense. Motorists would not feel that they must drive on a STA day because they may not be able to drive on a following day. The cooperation effect, should, therefore, be observable in this paper without any of these countervailing forces. The prospect of crowded buses and trains and attendant delays may, however, prompt some regular public transit riders to substitute toward cars.

Equation 1 is estimated with panel corrected standard errors to allow for panel heteroskedasticity and contemporaneous cross-sectional correlation. Panel heteroskedasticity and contemporaneous cross-sectional correlation do not affect the consistency of OLS point estimates but do bias estimated standard errors and may reduce the efficiency of OLS. Given the nature of the PeMS data, we assume the error variance is constant within group but varies across groups and that observations across stations in each period are not independent. Traffic volume at one location may depend on traffic volume at other stations because stations are located at different points along the same roadways and commute patterns. Specifically, we assume:

$$E(e_{it}^2) = E(e_{is}^2) = \sigma_i^2,$$
$$E(e_{it}e_{jt}) = E(e_{is}e_{js}) = \sigma_{ij}, i \neq j, \quad E(e_{is}e_{jt}) = 0, i \neq j, s \neq t.$$

And we do not assume:

$$E(e_{it}^2) = E(e_{jt}^2), i \neq j.$$

We further assume no serial correlation of the errors. Following Beck and Katz (1995), we derive the sample variance of OLS estimates from the following variance-covariance matrix:

$$Cov(\hat{\beta}) = (X'X)^{-1}X'(\hat{\Omega})X(X'X)^{-1},$$

where

$$\hat{\Omega} = \frac{E'E}{T} \otimes I$$

and E is a $T \times N$ matrix of OLS residuals. This methodology will generate consistent OLS estimates and unbiased estimates of variability.

Using the same methodology, we also estimate:

$$TVit = \alpha_i + \beta_1 STA_t + + \beta_2 TEMP_t + \beta_3 HOLIDAY + \sum_{i=1}^{6} \gamma_i DAY_i + \sum_{j=1}^{4} \phi_j MONTH_j + \sum_{k=1}^{3} \delta_k YEAR_k + \varepsilon_{it.} \tag{1.1}$$

Equation 2 differs from Equation 1 only in that it excludes a control for free fare STA days. Whereas in Equation 1 we can separately estimate the effect of the STA day declaration (the cooperation effect) and the effect of free transit (price effect), Equation 2 estimates the overall effect of STA over the past four years.

We estimate Equations 1 and 2 in the same manner for bridge data, correcting standard errors for panel heteroskedasticity and contemporaneous cross-sectional correlation. In addition, we estimate two equations for each bridge separately as follows:

$$TV_t = \alpha + \beta_1 STA_t + \beta_2 STAFREE_t + \beta_3 TEMP_t + \beta_4 HOLIDAY + \sum_{i=1}^{6} \gamma_i DAY_i + \sum_{j=1}^{4} \phi_j MONTH_j + \delta Y2006 + \varepsilon_t \tag{1.2}$$

$$TV_t = \alpha + \beta_1 STA_t + \beta_3 TEMP_t + \beta_4 HOLIDAY + \sum_{i=1}^{6} \gamma_i DAY_i + \sum_{j=1}^{4} \phi_j MONTH_j + \delta Y2006 + \varepsilon_t \tag{1.3}$$

where Y2006 is the only year control because data are limited to 2006 and 2007. Because there is no cross-sectional variation in the covariates included in (1) and (2), the coefficients on STA (and STAFree) constitute means of the coefficients when (1) and (2) are estimated separately for each group, as in (3). Whereas reporting the coefficients from these separate equations provides little insight for the PeMS data, it is possible to determine with bridge data if the STA effect is greater on bridges that serve commute routes with attractive public transit options. We expect that STA effects will be greatest on the SFOBB—the only route across the San Francisco Bay Area that is also served by BART. (2) is estimated by OLS with White robust standard errors.

6. RESULTS

Estimation results are reported in Table 2 For the most part, we find that the STA program has no significant effect on traffic volumes in the Bay Area. We find significance of the STA program on two bridges estimated by (3) and (4).

With estimation by (1) and (2) using PeMS data, we find the STA program has no significant effect on traffic volumes. Our point estimates show that free fare days are associated with greater reductions in car traffic than STA days that do not include free transit rides. In these estimations, all control variables are significant at the 95% level and of the correct sign. Likewise, estimation of (1) and (2) using bridge data finds no significant effect of STA. Most, but not all, control variables are significant at the 95% significance level. STA is found to have a significant effect on traffic volumes on the Richmond bridge. Estimation by (4) finds a 538-car reduction in traffic at Richmond on STA days. Estimation by (3) finds free fare STA days to have a significant 1275-car reduction at Richmond. STA days without free fares have no significant effect when estimated by (3). Finally, we find significant effects of STA and free fare STA on the San Mateo bridge when estimating (3). Notably, STA days are associated with a 1262-car *increase* in traffic whereas free fare STA days reduce traffic by 2117 cars.

It is interesting, though not *a priori* surprising, that STA has significant effects at two bridges but not Bay Area wide. Trans-bay passenger-car commutes can, in some circumstances, be more easily substituted with transit service than other types of commutes, which may be likely to include a series of transfers. BART, for instance, serves the same route as the SFOBB. It is, however, surprising that the SFOBB does not see significant reductions in traffic volumes while the Richmond and San Mateo bridges do. Understanding why these bridges experience significant STA effects is the subject of additional inquiry.

7. DISCUSSION

The foregoing econometric analysis suggests the STA program does not have much impact on the transportation decisions of residents in the San Francisco Bay Area. Transportation and commute patterns typically become habit and even free public transit may be insufficient to entice commuters out of their routines. These findings suggest that appeals for cooperation, in this context, do not effectively achieve the goals of social planners. This work, therefore, is consistent with findings that appeals for conservation of energy and flu vaccines may fail.

Policymakers have used a variety of mechanisms, both pecuniary and non-pecuniary, to reduce air pollution. Our econometric estimation can be used to determine how the STA program compares to other air pollution reduction programs. We estimate the STA reduction in ozone-causing pollution by converting our point estimates for traffic-volume-reductions to percent reductions based on mean daily traffic for each data source (and for each bridge for bridge-specific estimates). Following the methodology of the BAAQMD (BAAQMD 2005), we multiply our estimated percent reductions in traffic volumes by the total number of daily car trips in the Bay Area (as estimated by the MTC). We also multiply by the average vehicle miles travelled per car trip to determine the STA-induced reduction in vehicle miles travelled. Then, based on analysis from the California Air Resources Board, we calculate the reduction in nitrogen oxide (N0x), reactive organic gases (ROG) and particulate matter 10 (PM10), three forms of air pollution that principally constitute smog. The equations used to estimate the change in these ozone-causing emissions are included in Appendix C. Results of this analysis are summarized in Table 3.

Based on estimates from PeMS data (which are not significant at the 95% significance level), we conclude that for the past four years, the STA program has eliminated 533,674 car trips in the Bay Area per STA day and reduced vehicle miles traveled by 616,397 miles per STA day. The cooperation effect of STA is associated with a 46,286-car *increase* in traffic volumes per STA day, whereas free transit rides on STA days reduce car trips by 1,351,054. Using our only statistically significant STA effect from the Richmond bridge and extrapolating the effect to the Bay Area writ large, we conclude that the average STA day reduces car trips by 264,731 vehicles. Based on significant effects from the Richmond and San Mateo bridges, the STA price effect is between 627,070 and 786,520 cars per free fare day. This offsets increases in traffic volumes on non-free-fare STA days of between 155,978 and 468,781. Our estimate of the effect of non-free fare STA days—the cooperation effect—is significant at the San Mateo bridge. STA *increases* car trips, meaning that any cooperation effect is dominated by demand-increasing behaviors, which we suspect to be inconsequential in this case. Non-free fare STA days increase trips by more than 540,000 cars. This result may reflect aversion from regular transit commuters to ride on STA days, which are more crowded and more prone to run behind schedule. It may also reflect a peculiarity of the particular bridge, and, therefore, highlights the hazards in extrapolating from one bridge to the entire set of Bay Are commute paths.

These results suggest BAAQMD may have significantly overstated the effectiveness of STA in its 2006 report. In particular, whereas they estimate average car-trip reductions of 345, 299 car trips (in 2005) and 348,244 (in 2004) per STA day, our analysis of PeMS data suggest an insignificant reduction of only 46,286 cars.

Table 3 also summarizes the cost of STA per reduced car trip and reduction in NOX, ROG, and PM10 emissions, respectively. Based on the range of estimates of the STA effect from our various estimation procedures, we find that the cost per STA-free-fare-reduced car trip is between \$3.18 and \$21.37. The cost per reduced ton of smog-causing pollutants is between \$400,000 and \$7.6 million. Our PeMS-based estimate of the cost per ton of NOX reductions from free fare STA days suggests BAAQMD may have understated the cost per ton of STA by an order of magnitude (BAAQMD 2006). Our analysis further suggests that the STA program is among the most expensive and least efficient air-pollution-reduction policies pursued in California and the U.S. Each ton of STA-reduced NOX emissions, for instance, is estimated to cost between \$422,000 (from San Mateo bridge estimation) and \$2.8 million (from PeMS). Though not aimed at immediate and short-term reductions (to avoid exceeding EPA smog standards), several programs have been found to offer greater reductions in pollution per dollar spent. Such programs include car scrappage programs, which offer financial incentives for removing old cars from roadways, and bus and truck retrofit programs that replace old engines with cleaner technologies. In California, the Air Resources Board's Carl Moyer program offers grants to adopters of clean engine technology. The program is found to reduce NOX emissions at an average cost of \$2,500 per ton. The state requires grants be allocated only to programs that will receive emissions reductions at less than \$13,600 per ton. The Tennessee Valley Authority has achieved NOX reductions for \$2,917 per ton by installing selective catalytic reduction equipment at its coal-fired power plants (TVA 2007).

8. CONCLUSION

This paper presents the first objective analysis of the effectiveness of the Spare the Air program in the San Francisco Bay Area. It uses data on traffic volumes to determine the extent to which cooperation and pecuniary incentives reduce car trips on STA days. In this respect, this paper contributes to a literature that examines the extent to which appeals for cooperation can lead to socially optimal levels of consumption and efficient allocation of scarce resources when price mechanisms do not function properly. Based on econometric estimates of the magnitudes of the cooperation and price effects of the STA program, we estimate the STA-induced reduction in ozone-causing pollution. We find that previous estimates of the effectiveness of the STA program are overstated. We further find that the cost per reduced ton of pollution is considerably greater under STA than under other air-pollution-mitigation programs. These results are relevant to policymakers in the San Francisco Bay Area and elsewhere (including the greater Sacramento, Calif. Region) that operate STA or similar programs. It should also be of interest to cities considering adopting similar programs, such as Los Angeles.

In future work, we intend to use hourly observations on traffic volumes from PeMS data to identify if effects are greater during commute hours, as we may expect. In addition, we intend to use public transit ridership data to determine if (a) commuters reschedule trips for free fare days, in which case ridership would be expected to decline following free fare days (For STA days, free fares are announced less than one day in advance, so postponing trips to free fare days would not be possible) and (b) if free fare days, which some argue help introduce the driving public to transit options, are successful in boosting regular transit ridership. The transportation literature suggests a lack of familiarity with transit options is responsible for the aversion of some commuters to using public transportation. Transit authorities have, therefore, begun to offer free fares in an effort to make transit more familiar. The BAAQMD and MTC, faced with funding for just one free fare day in 2008, planned to announce a free fare day unaffiliated with STA and abandon funding of free fare STA days for the year.

Table 2: Econometric Results

	PeMS		Bridges		Dumbarton (1)		Richmond (2)		SFOBB (3)		San Mateo (4)	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
STADay	194.313 (374.875)	-224.043 (163.239)	-387.102 (867.249)	-937.132 (547.735)	-96.288 (355.502)	-387.768 (228.383)	317.139 (415.184)	-538.256* (263.931)	-3065.779 (2209.569)	- 2685.045** (1385.775)	1261.849* (623.233)	-159.534 (396.671)
STADayFree	-491.070 (393.880)	--	-825.711 (1009.305)	--	-448.89 (419.6401)	--	-1274.969* (481.054)	--	566.981 (2560.084)	--	-2117.129* (722.272)	--
Holiday	-17966.7* (358.339)	-17932.63* (356.102)	-19018.67* (812.578)	-19028.33* (812.379)	-16451.41* (315.016)	-16456.85* (315.054)	-9654.987* (397.453)	-9669.441* (401.609)	-35688.96* (2112.043)	-35682.53* (2108.318)	-15332.01* (596.786)	-15356.24* (604.597)
Temp	13.5469* (5.270)	13.900* (5.282)	26.69** (13.977)	27.044** 13.968	10.603** (5.639)	10.783 (5.638)	21.601* (6.758)	22.139* (6.826)	63.2585** (35.777)	63.002** (35.698)	12.374 (10.07685)	13.315 (10.205)
Sunday	-18122.09* (140.953)	-18118.8* (141.557)	-15825.16* (391.119)	-15805.91* (390.356)	-15920.61* (160.044)	-15910.03* (159.778)	-8620.205* (187.362)	-8591.018* (189.011)	-24729.51* (1003.122)	-24743.32* (999.509)	-14144.98* (279.679)	-14097.02* (282.881)
Monday	-5933.325* (153.080)	-5930.901* (153.724)	-5113.764* (395.367)	-5107.282* (395.232)	-1349.74* (162.817)	-1346.019* (162.821)	-3591.385* (189.763)	-3581.455* (191.728)	-12840.87* (1003.131)	-12845.31* (1001.256)	-2717.122* (283.324)	-2701.128* (287.006)
Tuesday	-4364.817* (140.673)	-4364.538* (141.311)	-3609.322* (389.248)	-3590.498* (388.513)	-303.737** (160.708)	-292.769** (160.421)	-2806.58* (185.877)	-2778.458* (187.532)	-9512.925* (989.264)	-9525.585* (985.962)	-1792.93* (279.179)	-1745.382* (282.382)
Wednesday	-3359.992* (132.895)	-3364.902* (133.495)	-2764.99* (386.636)	-2764.673* (386.582)	-1.074 (159.08)	-.289 (159.118)	-2319.503* (185.25)	-2319.566* (187.204)	-7618.509* (985.682)	-7618.647* (984.036)	-1147.203* (276.414)	-1147.834* (280.059)
Thursday	-2239.183* (132.993)	-2245.081* (133.559)	-1552.238* (385.586)	-1569.46* (384.957)	423.677* (159.255)	417.041* (159.174)	-1463.216* (184.518)	-1492.178* (186.138)	-4834.449* (981.779)	-4821.74* (978.464)	-377.798 (275.4)	-426.413 (278.525)
Saturday	-10685.51* (135.672)	-10681.47* (136.320)	-9871.22* (390.299)	-9851.304* (389.485)	-12025.41* (159.82)	-12014.21* (159.516)	-4506.533* (188.447)	-4475.69* (190.072)	-13370.94* (996.334)	-13384.9* (992.678)	-9437.332* (278.045)	-9388.82* (281.212)
May	1627.993* (120.015)	1621.4* (120.476)	-609.102** (334.767)	-626.835 (334.0183)	-497.871* (136.764)	-507.053* (136..528)	-237.952 (160.679)	-265.031 (162.045)	- 1555.407** (854.964)	- 1542.518** (851.556)	-58.077 (240.533)	-103.755 (243.193)
June	1447.208* (126.863)	1437.76* (127.0626)	137.873 (338.536)	103.749 (335.91)	-153.345 (137.842)	-171.686 (136.806)	664.47* (162.189)	612.114* (162.68)	-896.984 (867.734)	-872.934 (859.475)	928.474* (243.656)	841.268* (245.021)
July	1092.15* (121.432)	1081.588* (121.6847)	339.933 (351.052)	322.224 (350.335)	-525.427* (142.164)	-533.445* (-142.002	482.798* (168.818)	454.733* (170.263)	1177.946 (898.875)	1191.382 (895.328)	287.818 (253.65)	240.745 (256.479)
Aug	1421.869* (118.721)	1406.605* (118.594)	773.531* (343.503)	743.676* (341.512)	-422.113* (139.5412)	-438.0905* (138.531)	766.648* (165.005)	720.936* (165.833)	1777.929* (881.612)	1799.196* (874.903)	994.359* (246.974	918.324* (248.847)
Y2004	3160.959* (108.233)	3163.147* (108.687)	--	--	--	--	--	--	--	--	--	--
Y2005	3701.765* (102.511)	3697.283* (102.975)	--	--	--	--	--	--	--	--	--	--
Y2006	724.7146* (105.354)	737.550* (105.337)	528.622* (211.739)	541.4645* (211.1268)	873.009* (86.7)	879.1645* (86.53)	371.017* (101.706)	391.252* (102.49)	-408.849 (539.475)	-418.2806 (536.893)	1196.469* (152.066)	1229.793* (153.64)
Intercept	77832.81* (444.683)	77808.4* (446.171)	63330.71* (1175.764)	63307.81* (1175.266)	34235.8* (477.429)	34223.53* (477.411)	36958.63* (567.719)	36924.34* (573.559)	132345* (2996.187)	132361.4* (2990.273)	49806.97* (846.537)	49746.88* (857.447)

* Denotes significance at the 95% significance level. Standard errors are in parentheses.

** Denotes significance at the 90% confidence level

Table 3: Estimated STA Reductions in Bay Area Traffic and Pollution Emissions

Estimation Procedure (Equation #)	Coefficient	Percent Change in Car Trips	Change in Total Bay Area Car Trips	Change in Total Bay Area Vehicle Miles Travelled	Change in NOX (in tons)	Change in ROG (in tons)	Change in PM10 (in tons)	Cost per reduced trip (in US$)[1]	Cost per reduced ton NOX (in US$)	Cost per reduced ton ROG (in US$)	Cost per reduced ton PM10 (in US$)
PeMS Data											
(1)	STA	0.26	46285.96	534602.87	0.35	0.31	0.13	--	--	--	--
	STA Free	-0.66	-116974.41	-1351054.40	-0.88	-0.78	-0.33	21.37	2840436	3209916	7675890
(2)	STA	-0.30	-53367.74	-616397.42	-0.40	0.36	-0.15	30.36	4050000	4500000	10800000
Bridges											
(1)	STA	-0.64	-113462.50	-1310491.83	-0.85	-0.76	-0.32	--	--	--	--
	STA Free	-1.37	-242022.08	-2795355.02	-1.82	-1.61	-0.67	10.33	1372843	1551420	3709921
(2)	STA	-1.56	-274680.41	-3172558.73	-2.07	-1.83	-0.76	5.90	782609	885246	2131579
Richmond											
(3)	STA	0.88	155978.99	1801557.32	1.17	1.04	0.43	--	--	--	--
	STA Free	**-3.56**	**-627070.07**	**-7242659.31**	**-4.72**	**-4.18**	**-1.75**	**3.99**	**529858**	**598782**	**1431870**
(4)	**STA**	**-1.50**	**-264731.32**	**-3057646.76**	**-1.99**	**-1.76**	**-0.74**	**6.12**	814070	920455	2189189
San Mateo											
(3)	**STA**	**2.66**	**468780.92**	**5414419.63**	**3.53**	**3.12**	**1.31**	**--**	**--**	**--**	**--**
	STA Free	**-4.46**	**-786520.16**	**-9084307.89**	**-5.92**	**-5.24**	**-2.19**	**3.18**	**422441**	**477391**	**1141589**
(4)	STA	-0.34	-59267.39	-684538.34	-0.45	-0.39	-0.16	-27.33	3600000	4153846	10125000

Note: Bolded entries denote results based on statistically significant point estimates

[1] Average cost per free fare STA day is $2.5 million (BAAQMD). STA Free analysis is based on this cost. The average cost per STA day (free and not free) over sample period is $1.62 million. STA analysis by (2) is based on this cost.

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Appendix A:

STA Free Fare Participating Transit Agencies

AC Transit
ACE
Alameda-Harbor Bay Ferry
Alameda-Oakland Ferry
Air BART
BART
Benicia Breeze
CalTrain
Cloverdale Transit
County Connection (CCCTA)
Dumbarton Express
Fairfield/Suisun Transit
Golden Gate Ferry and Bus (GGBHTD)
Healdsburg Transit
Wheels
Marin County Transit
MUNI
Napa VINE
Petaluma Transit
Rio Vista Delta Breeze
SamTrans
Santa Rosa City Bus
Sonoma County Transit
Tri Delta Transit
Union City Transit
Vacaville City Coach
Vallejo Transit and Vallejo Baylink Ferry
VTA
WestCat

Free Fare Restrictions

2004	None
2005	Must enter transit system by 9AM
2006	None
2007	Must enter transit system by 1PM

STA Days (*Denotes Free Fares)

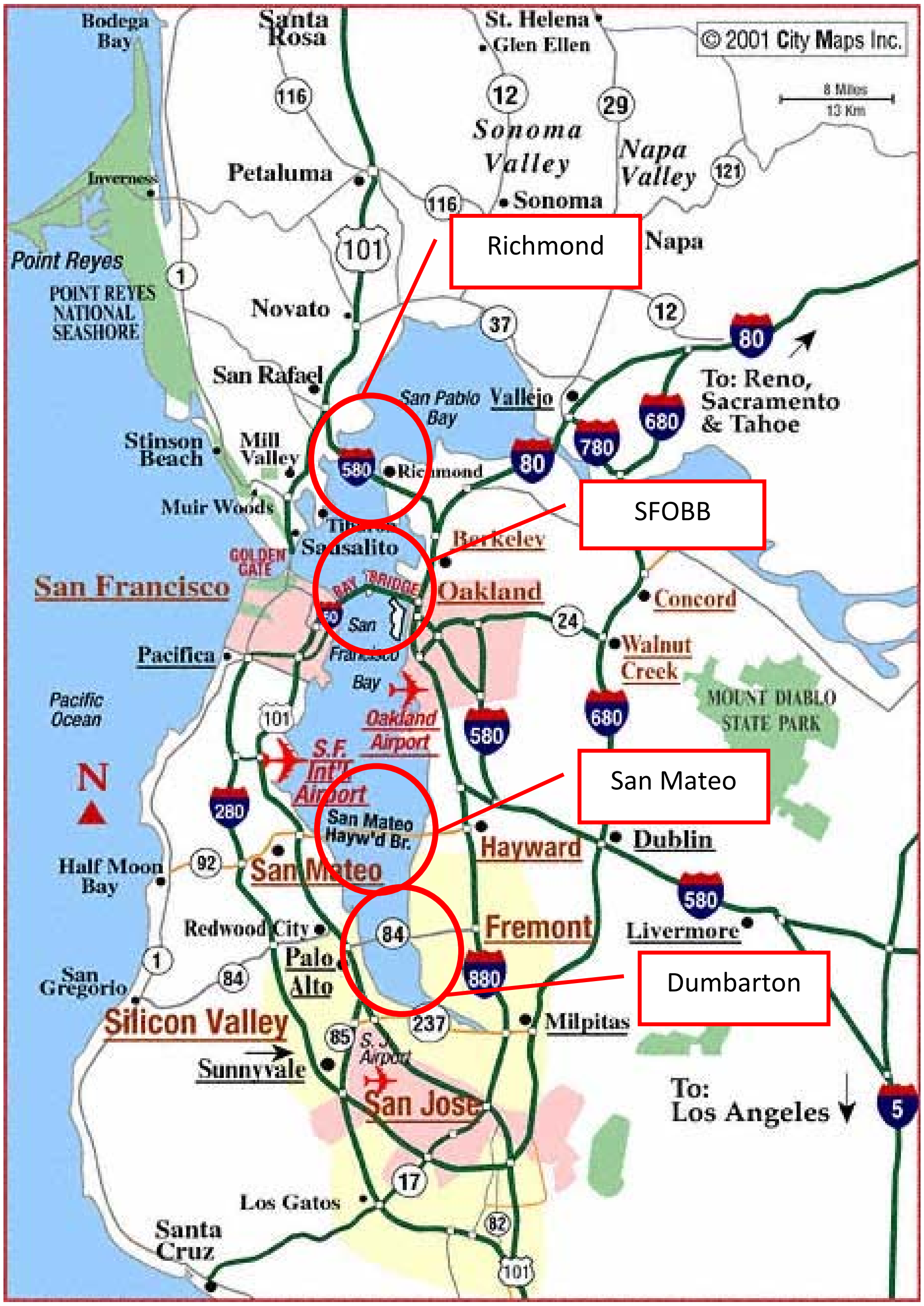
Aug. 29 2007*

Aug.	**30**	**2007***
Sep	**12**	**2006**
Sep.	**01**	**2006**
July	**24**	**2006**
July	**23**	**2006**
July	**22**	**2006**
July	**21**	**2006***
July	**20**	**2006***
July	**17**	**2006***
June	**26**	**2006***
June	**23**	**2006***
June	**22**	**2006***
July	**25**	**2005***
Sep.	**08**	**2004***
Sep.	**07**	**2004***
Sep.	**06**	**2004**

Appendix B:

Map of Cal Trans District 4

Map of Bay Area Bridges



Appendix C:

Procedure of Estimates of STA Effect On Ozone-causing Car Emissions

NOX Emissions:

Total NOX = (%ΔTraffic Volume x 17,637,500[2]) x (0.612grams[3] + 11.552[4] x 0.538grams[5])

ROG Emissions:

Total ROG = (%ΔTraffic Volume x 17,637,500) x (1.143grams[6] + 11.552 x 0.424grams[7])

PM10 Emissions:

Total PM10 = (%ΔTraffic Volume x 17,637,500) x (0.008grams[8] + 11.552 x 0.218grams[9])

[2] Estimated total daily car trips in San Francsico Bay Area (MTC).
[3] NOX emissions per time a car is started (California Air Resources Board).
[4] Average vehicle miles travelled per car trip in San Francsico Bay Area (MTC).
[5] NOX emissions per time vehicle mile travelled (California Air Resource Board).
[6] ROG emissions per time a car is started (California Air Resources Board).
[7] ROG emissions per time vehicle mile travelled (California Air Resource Board).
[8] PM10 (particulate matter) emissions per time a car is started (California Air Resources Board).
[9] PM10 (particulate matter) emissions per time vehicle mile travelled (California Air Resource Board).