Title

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Abstract

Policy-makers have relied on non-coercive mechanisms to achieve socially optimal outcomes in a variety of contexts when prices fail to ration scarce resources. Amid heightened concern about environmental damage and climate change, public appeals for cooperation and pecuniary incentives are frequently used to achieve resource conservation and other prosocial behavior. Yet the relative effectiveness of these two instruments is poorly understood when pecuniary incentives are small. This paper examines the extent to which free transit fares and appeals for car trip avoidance reduce car pollution on smoggy days. Using data on freeway traffic volumes and transit ridership, public appeals for cooperation are shown to reduce car trips. The marginal effect of free transit fares, however, is to *increase* car trips. Public appeals are shown to increase carpooling but not transit ridership. Free fares increase transit ridership but not carpooling. These results suggest that free transit rides do not induce motorists to substitute to transit, but instead subsidize regular transit rides and additional trips. They support findings in the behavioral literature that extrinsic incentives can crowd-out altruism.

1 Introduction

Appeals for cooperation and pecuniary incentives are used in a variety of settings to reduce depletion of scarce resources that are not properly rationed by prices, either due to missing markets or demand-invariant and fixed prices. During World War I, the U.S. government urged citizens to aid the war effort by planting "victory" gardens and conserving food. In World War II, citizens were asked to dress warmly to conserve fuel and to collect aluminum cans to be converted into ammunition. More recently, conservation has been urged amid shortages of energy, water, and medical supplies. These mechanisms have become increasingly common amid heightened concern about environmental damage and increasing scarcity of traditional water and energy resources. They are also used in the context of climate change mitigation, wherein the quantity of environmentally acceptable greenhouse gas emissions is constrained by the greenhouse effect. Whereas explicit rationing and coercive screening can be controversial and politically unsustainable responses to shortages, voluntary conservation programs are generally more acceptable. Whether they are effective is another matter–and the subject of a growing body of research that yields mixed results.

Voluntary conservation and pecuniary incentives are used in a number of localities across the United States to reduce atmospheric ozone concentrations on days when air pollution is expected to reach unsafe levels. While air quality has generally improved in recent years throughout the U.S., nearly half of all regions that monitor ground-level ozone periodically exceed federal standards for safe ozone concentrations. Because ozone levels peak on hot, calm, sunny days, ozone exceedances are seasonal and predictable. Therefore, they can be avoided with episodic pollution control regimes rather than permanent pollution-reduction programs, which can be more costly. This paper studies the effectiveness of non-coercive policy mechanisms in the context of the Spare the Air (STA) program in the San Francisco Bay Area, which, like programs in other cities across the country, aims to reduce ozone pollution on bad air days by motivating motorists to reduce car trips. While the STA initially entailed only public appeals for car trip reduction, it later also provided free transit rides on smoggy days.

Previous studies of the effectiveness of these voluntary episodic pollution control programs produced conflicting results (Cummings and Walker 2000, Lu et al. 2004, Schreffler 2003, Welch et al. 2005). The work of Cutter and Neidell [2009], (henceforth C-N), most convincingly shows a statistically significant 2.5-3.5% decline in car trips as a result of the San Francisco STA program. This paper extends C-N and others in four ways ways. First, it disaggregates the overall effect of STA into an effect attributable to public appeals for cooperation and an effect due to free fares on public transit. Understanding the relative effectiveness of these two components of the STA is important for motivating behavior that is in the interest of society but not individually rational in the traditional sense. The separate estimation of these two incentives for cooperation supports behavioral theories that extrinsic incentives like rewards and punishments crowd-out altruism. It demonstrates that expenditures to fund free transit rides are actually counter-productive.

Second, this paper provides evidence on how car trip reductions are achieved. In particular, the STA program is shown to induce additional carpooling but not net increases in the use of public transit. Third, this paper presents evidence to suggest that cooperation is decreasing in the cost of cooperation. Specifically, STA-induced transit ridership gains decrease in distance to a central business district. Finally, this paper explores whether responsiveness to STA declines on successive STA days.

This paper proceeds in Section 2 with a review of the existing literature related to non-coercive rationing programs generally and episodic pollution control specifically. Section 3 provides an overview of the theory of car trip reduction. Section 4 describes the data and empirical approach of this paper. Section 5 presents empirical results. Section 6 concludes.

2 Literature Review

Appeals for cooperation and pecuniary incentives for prosocial behavior can allocate resources in socially beneficial ways by inducing voluntary conservation among resource-consuming populations. Such mechanisms are common in the context of environmental protection, where missing markets are a frequent problem and policies to correct market failures are rare. Appeals for conservation are also made following natural disasters like storms, fires and earthquakes when safe water, food, and shelter may be in short supply.

While voluntary conservation is more politically viable than coercive screening and more efficient than non-pecuniary cost rationing and quotas, it achieves social objectives only to the extent that it induces behavior that is not individually rational in the neo-classical sense. (Olson 1971, Hardin 1968). The costs of cooperation are borne by the cooperators, but benefits accrue to cooperators and shirkers alike, making cooperation subject to the free-rider and under-provision problems typically associated with public goods.

The effectiveness of non-coercive rationing depends upon the inducement of prosocial behavior among a subset of the target population. Prosocial behavior may be generated by intrinsic motivation, such as other-regarding preferences (pure altruism), utility from the "warm glow" of giving, (impure altruism), and benefits derived from social signalling (competitive altruism). It may also be induced by extrinsic motivations, such as rewards for pro-social behavior or punishments for anti-social behavior (Aaron and Schwartz 1990, Andreoni 1989, Batson and Powell 2003, Becker 1965, Benabou and Tirole 2006). Given that cooperation is expected to be under-provided, public appeals for conservation can have the perverse effect of increasing demand for scarce resources by increasing salience and inducing hoarding (Adelman 2004, De Janvry et al. 2008, Folger 1992, Lynn 1992). Similarly, extrinsic rewards, like pecuniary incentives, can have the perverse effect of reducing cooperation by crowding out intrinsic motivation (Benabou and Tirole 2006, Ariely et al. 2009, Frey and Jegen 2001, Janssen and Mendys-Kamphorst 2004).

With theory providing inconclusive predictions about the impact of non-coercive rationing, the determination of its effectiveness is the domain of empiricists. Attempts have been made in a variety of settings to determine whether appeals for conservation reduce demand from a cooperative public, or whether they induce greater demand from consumers afraid of resource depletion. Much of the early work in this regard surrounds energy conservation efforts during the energy crisis induced by the Arab oil embargo of 1974. Controlling for price effects with a difference-in-differences approach, Peck and Doering III [1976] found no reduction in home energy demand due to appeals for conservation.Mayer [1978], however, attributed a ten-percent decrease in home energy use in New Jersey in 1974 to cooperation and changing social norms. Taylor et al. [1984] found that 29 states consumed less energy during the crisis than expected on the basis of demand forecasts and realized prices; only two states consumed less energy than expected one year before the crisis. More recently, Reiss and White [2008] reported that a conservation campaign during the California energy crisis of 2000-01 generated a prolonged 6% drop in demand.

De Janvry et al. [2008] investigated the response to a public appeal for cooperation at UC Berkeley during the 2004 U.S. flu vaccine shortage. Members of the campus community were asked to refrain from getting scarce flu shots in order to save them for at risk groups like the elderly and infirm. They found that provision of information about scarcity had the effect of increasing demand due to increased salience of the scarce commodity and decreased procrastination in getting shots. The increase in demand was only partly offset by self-restraint exhibited by some individuals.

A number of regions across the country, including two air quality districts in California, operate voluntary episodic pollution control programs that appeal to motorists to reduce car trips on smoggy days. When pollution damages are seasonal and predictable, episodic controls may achieve pollution reductions more cost-effectively than permanent controls. Because of the nature of ozone formation, ozone pollution is well-suited for episodic control. The extant literature includes several analyses of these programs. Schreffler [2003] used telephone surveys on daily travel activities to infer a 4.8% reduction in car trips due to the STA. Cummings and Walker [2000] found no significant effect of a program in Atlanta, GA, while Welch et al. [2005] observed that a program in Chicago increased traffic volumes during peak demand and reduced traffic volumes during off-peak hours. C-N improved upon the self-reports of Schiefer and corrected deficiencies in the econometric specifications of Cummings and Walker [2000] and Welch et al. [2005]. In their analysis of the STA, C-N estimated a 2.5-3.5% reduction in traffic volumes due to STA. Their results also indicated some substitution toward public transit and supported their theory that discretionary trips are more likely to be avoided than work-related commutes.

This paper follows the methodology of C-N and uses similar data. It extends their analysis in several key ways. First, whereas C-N analyzed data from 2001 to 2004, this paper draws on data from 2002 through 2009, which not only permits a more current estimate of program effectiveness but also exploitation of a change in the program in 2004 that made free transit rides available on some STA days. This change in program parameters enables separate estimation of the effectiveness of pecuniary incentives and public appeals. Second, data unique to this paper also permit a separate estimation of the effect of STA on carpooling, which provides important information as to how motorists respond to STA and yields valuable insights into other results of this and previous analyses. Third, this paper investigates whether responsiveness to STA declines on consecutive STA days. Finally, it explores how cooperation varies with distance to transit stations, including high-speed commuter-rail stations, train stations and bus stops. It also considers the effect that distance to the central business district in downtown San Francisco has on trip avoidance behavior.

3 Theory of STA trip reduction

STA succeeds in reducing vehicle pollution on smoggy days to the extent that it induces motorists to either carpool, use transit, or take fewer trips. Like other appeals for cooperation, STA relies upon altruistic preferences to motivate car trip reductions. If the sole effect of STA were to elicit prosocial behavior among altruists, then the program should reduce car trips and increase carpooling and transit demand.

Indirect effects associated with STA alerts, however, may lead to increased demand for car trips and less demand for transit. For instance, STA alerts may function as warnings about air pollution, triggering transit passengers to substitute to car trips in order to minimize exposure to bad air. Would-be transit riders may also opt for car trips on STA days in order to avoid expected congestion on mass transit caused by the public appeals. Furthermore, while neo-classical theory holds that adding pecuniary incentives like free fares to the intrinsic incentives of STA alerts should increase cooperation, evidence in the behavioral literature suggests it may decrease cooperation by clouding the social signal from cooperation and lessening the sense of civic duty (Gneezy and Rustichini 2000a,b, Akerlof and Dickens 1982, Frey and Palacios-Huerta 1997, Frey and Jegen 2001, Benabou and Tirole 2006).

C-N developed a model of utility maximizing travelers who can choose to drive, take transit, or not travel. Utility is defined over consumption of a composite good, health, "environmental altruism", and travel time, where health is decreasing in exposure to bad air and exposure is greater for trips made by transit than by car. STA serves as a signal of poor air quality, which is assumed to be otherwise unobserved.[1] Travel time by car is assumed to be lower on STA days due to less congestion, while travel time by transit is assumed to be unchanged. Given this framework, utility from not traveling increases on STA days because of "warm glow" and diminished exposure to ozone. Utility from transit rides may either increase or decrease depending on whether utility from warm glow exceeds disutility from exposure to smog. Expectations of reduced travel time for car trips (due to reduced congestion) *increases* utility from car trips on STA days in the C-N model.

This paper departs from the C-N framework by considering several additional effects that may influence the overall impact of an STA declaration, including the possibility that travelers respond by using carpools. Travelers' consideration of congestion effects on both highways and public transit may be an important factor influencing trip decisions and mode choice. These congestion effects are market-level effects, whereas the C-N model is focused solely on the utility of individual travelers. It is reasonable to assume that travel times for both transit and car trips are increasing in the number of total trips made via the respective modes, as is inconvenience associated with travel by public transit. If STA is expected to induce additional demand for transit, then expected travel time on transit increases, causing some transit riders to substitute to car trips or no trips. Thus, trip decisions and mode choice based on expectations about these market effects, can lead to unintended outcomes, like increased car trips.

To incorporate expectations of market impacts and the choice of carpooling in response to an STA declaration, consider the following adaptation of the C-N model. Assume that each individual chooses from among car (C), carpool (CP), public transit (PT), and no trip (NT) for each travel opportunity. The individual chooses the mode that yields the maximum utility among the available options. Thus, for individual i we have:

$$U_i = \max\left\{U_i^C, U_i^{CP}, U_i^{PT}, U_i^{NT}\right\},$$

where $U_i^C, U_i^{CP}, U_i^{PT}$ and U_i^{NT} denote individual i's utility from each trip mode. Let $T_i^j = 1$ if $U_i^j = \max\left\{U_i^C, U_i^{CP}, U_i^{PT}, U_i^{NT}\right\}$ and $T_i^j = 0$ otherwise, for $j \epsilon \{C, CP, PT, NT\}$. Then define market demands as:

$$Q^j = \sum_i T_i^j$$

for j defined as above. Each trip mode j generates intrinsic utility for individual i, V_i^j. A constant utility U^0 is also derived from each unit of consumption of a composite commodity with price equal to 1.0.

Utility from each trip mode net of the impact on consumption of the composite commodity is given by:

$$U_i^C = V_i^C - f\left[t^c(Q^C, Q^{CP})\right] - P^C U_i^0 \tag{1}$$

$$U_i^{CP} = V_i^{CP} - f\left[t^{CP}(Q^C, Q^{CP})\right] - P^{CP} U_i^0 + s_i^{CP}(STA) \tag{2}$$

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[1] The federal Clean Air Act requires metropolitan statistical areas with populations greater than 350,000 to report air quality information and provide detailed reports to local media. While air quality forecasts are typically provided with weather forecasts in major metropolitan newspapers, such information may lack the salience of STA alerts, which are often reported on local newscasts and radio news reports.

$$U_i^{PT} = V_i^{PT} - f\left[t^{PT}(Q^{PT}), G(Q^{PT})\right] - P^{PT}U_i^0 + s_i^{PT}(STA, P^{PT}) - h_i\left[t^{PT}(Q^{PT}), STA\right], \tag{3}$$

$$\text{and } U_i^{NT} = V_i^{NT} + s_i^{NT}(STA), \tag{4}$$

where P^j denotes the inclusive pecuniary cost of transit mode j for $j \epsilon \{C, CP, PT, NT\}$. Equations 1-3 incorporate that car trips, carpools and public transit involve disutility from time spent in transit, t^j, which is a function of the total demand for travel by that trip mode.[2] The presence of carpool lanes means that car and carpool travel times may differ. Public transit trips cause disutility from transit time and from congestion, G, which is also a function of total demand, Q^{PT}. Carpools, public transit and trip avoidance (NT) are all associated with utility from the "warm glow" effect, s_i^j, on STA days. The effect may vary by transit mode. In particular, free fares may diminish the warm glow from public transit trips. PT also exposes users to an expected adverse health effect, $h_i\left[t^{PT}(Q^{PT}), STA\right]$, which is a function of exposure to outside air, as determined by transit time and STA status, which serves as a proxy for air quality.

STA impacts behavior only to the extent it motivates a mode switch among individuals. As equations 1-4 demonstrate, the impacts of STA on trip mode choice are complex. Notably carpooling, a mode option not investigated by C-N, unambiguously yields higher utility on a STA day due both to the presence of warm glow and a likely reduction of congestion on the roadways. Travel by private car, of course, yields no warm glow, but the absolute utility from car travel rises if road congestion declines. Although a clear goal of policy makers is to divert travelers to public transit on STA days, equation 3 shows that the impact of an STA declaration on utility from PT travel involves offsetting factors for the typical individual. Choosing PT yields a warm glow, but travelers may anticipate loss of utility from trip delays and congestion. They may also anticipate a negative health impact from exposure to outdoor conditions on days where such exposure is deemed unhealthy by the STA declaration. Making transit fares free on STA days augments the net utility from choosing public transit, but free fares may reduce the warm glow consumers receive from their altruistic behavior.

Equations 1-4 also make clear that trip time and congestion impacts are determined at the market level, based upon the aggregate impacts of individuals' actions. Because individuals must commit to their travel mode choice before actually observing these aggregate effects, their decision must be based upon expectations formed by past experiences with STA days and media coverage. Given the counterveiling effects associated with STA that are described in equations 1-4, determination of the net-effect of STA on traffic volumes is an empirical question. The next section presents a strategy to estimate the effect of STA and free fares on car trips, carpooling, and transit ridership.

4 Econometric Specification and Data

STA days are not exogenously assigned. Rather they are determined by forecasts of the Air Quality Index (AQI), a measure of air quality defined by the U.S. Environmental Protection

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[2] C-N assume away transit time costs associated with elevated demand for public transit on STA days because transit is intended to operate on fixed schedules. However, elevated demand increases both the frequency and duration of stops to board and disembark passengers. If trains and buses are filled to capacity, then transit riders may be delayed by waiting for subsequent buses and trains.

Agency. AQI is correlated with contemporaneous and forecasted weather characteristics that influence trip demand and transit-mode decisions. Air quality may, itself, impact trip demand. If all determinants of trip demand that are potentially correlated with AQI are observable and enter into trip utility linearly (as in the C-N model), then identification of STA effects may be achieved by including the covariates in a standard linear regression. However, if some determinants of trip decisions are correlated with AQI and are unobservable or enter non-linearly into trip demand, then STA estimates based on simple linear methods are biased. Because STA days are declared nearly completely on the basis of an administrative decision rule using a threshold AQI, the regression discontinuity design (RDD) can be employed to overcome the correlation between AQI and other determinants of trip demand in order to identify the STA effect. The RDD requires only that the association between AQI and trip demand evolve smoothly around the administrative threshold.

Individual changes to trip choices on STA days are not observed. Instead, we observe daily (and in some cases, hourly) aggregate volumes of car traffic, carpool traffic, and trips on the Bay Area Rapid Transit (BART) commuter rail service. Consequently, we specify an aggregate trip demand equation according to:

$$q_{it} = \beta_{5,1} STA_t + \boldsymbol{\delta} \mathbf{Z_t} + \boldsymbol{\gamma} \mathbf{D_t} + \xi q_{it-1} + \theta_{it} + \mu_{it}, \tag{5}$$

where subscripts i and t denote traffic-monitoring station and day, respectively, q_{it} denotes traffic volume and STA_t is a treatment indicator equal to one if day t is an STA day and zero otherwise. The vector $\mathbf{Z}$ represents daily contemporaneous and lagged weather characteristics, including high and low temperatures and precipitation, and forecasted sky conditions (i.e. clear, sunny, cloudy, etc.) and precipitation. The vector $\mathbf{D}$ denotes dummy variables for day of the week (i.e. Monday, Tuesday, etc.) and a month-year interaction (i.e. June 2002, July 2002, etc.). θ_{it} is a monitor-specific fixed effect, and μ_{it} is an idiosyncratic error. As in C-N, a one-day lag of traffic volume is included to control for transitory station-specific shocks, like road construction. The coefficient of interest is $\beta_{5,1}$, the estimate of the population-averaged effect of STA on car trips, carpooling, and transit.

Equation 5 is similar to Equation 5 in C-N. However, whereas C-N preferred a random effects (RE) model, the preferred specification in this paper is a fixed-effects (FE) approach, which controls for unobserved heterogeneity, including spatial autocorrelation. Because the cross-sectional units of observation in the present paper and in C-N exist along transit networks, they are likely to exhibit spatial autocorrelation or other forms of spatial dependence. Unless this spatial correlation is accounted for in estimation of the variance-covariance matrix, then standard errors will be too small. In essence, each cross-sectional observation is assumed to contain more information than it actually does. Fortunately, this analysis is not concerned with estimating time-invariant determinants of traffic volumes, so the within transformation can be used to difference out the spatial dependence so long as it primarily enters through the composite error (Wooldridge 2003, 2006). In the presence of spatial dependence of this form, the FE estimator is consistent, but the RE estimator is not. The RE estimator can lead to incorrect inference.

In order to separately determine how travelers respond to public appeals and free transit fares, this paper exploits variation in the use of free fares during the recent history of the STA program. The use of free fares in conjunction with public appeals is conditional on funding to reimburse regional transit agencies for foregone fare revenue. The availability of funding generates exogenous variation in the use of free fares both across years and within years. The marginal effect of free fares on traffic volumes is estimated by:

$$q_{it} = \beta_{6,1} STA_t + \beta_{6,2} FREE_t + \boldsymbol{\delta}\mathbf{Z_t} + \boldsymbol{\gamma}\mathbf{D_t} + \xi q_{it-1} + \theta_{it} + \mu_{it}, \tag{6}$$

where (6) is identical to (5) except for the addition of $FREE_t$, an indicator equal to one if free fares are offered in conjunction with STA and zero otherwise. If free fares provide an additional inducement for motorists to substitute to transit, then the marginal effect of free fares should be to reduce car trips. However, to the extent free fares crowd-out altruism or lead to congestion costs on transit, then traffic volumes may increase. Absent market effects, the extrinsic motivation from free fares should increase transit ridership because of increased substitution from car trips and carpooling and the inducement of additional trips as transit trips are substituted for no trips. Free fares may crowd-out intrinsic motivations (i.e. diminish altruism) for substitution to transit trips.

Two other dimensions of STA-response are explored in this paper. First, motivated by Graff Zivin and Neidell [2009], this paper considers traveler fatigue associated with consecutive STA days[3]. Individuals may be able to reduce car trips on STA days by postponing them to subsequent days. Such individuals may grow impatient if multiple STA days are declared consecutively, leading to diminished effectiveness of STA after the first in a series of STA days. Similarly, motorists may be willing to substitute to carpools or transit periodically, but be unwilling to do so repeatedly. To test for the presence of STA fatigue, we also estimate:

$$q_{it} = \beta_{7,1} STA_t + \beta_{7,2} FREE_t + \beta_{7,3} STA_t^{Con} + \beta_{7,4} FREE_t^{Con} + \boldsymbol{\delta}\mathbf{Z_t} + \boldsymbol{\gamma}\mathbf{D_t} + \xi q_{it-1} + \theta_{it} + \mu_{it}, \tag{7}$$

which is identical to (6) except for the addition of the indicators STA^{Con} and $FREE^{Con}$, where the former is equal to one if an STA day is immediately preceded by an STA day and the latter is equal to one if a FREE day is immediately preceded by a FREE day. Both STA^{Con} and $FREE^{Con}$ are otherwise equal to zero. If STA fatigue occurs, then these marginal effects should be of the opposite sign of the main effects (STA and $FREE$), i.e. if the main effects are to reduce traffic volumes or increase BART ridership, then the coefficients on each of these indicator variables should be positive in analysis of traffic data and negative in analysis of BART data. Consecutive STA days occur only 2% of the time during the STA season. Conditional on an STA day occurring, however, the probability that it will be followed by at least one consecutive STA day is 0.44. Likewise, consecutive FREE days occur only 0.6% of the time during the STA season, but conditional on a FREE day occurring, the probability that it is preceded by a FREE day is 0.67.

Finally, this paper investigates whether cooperation is diminished at locations farther from the central business district (CBD) and at locations farther from BART, train, and bus stations. This is accomplished by interacting station-specific measures of distance (DIST) to the downtown and to the nearest BART station, train station, and bus stop with the STA indicator.[4] Specifically, we estimate the impact of distance to transit stations and to the CBD using variants of (6) as given, respectively, by:

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[3] They find evidence that the cost of intertemporally substituting activities is increasing over time: when smog alerts are issued on two successive days, any response on the first day has largely disappeared by the second day. Small reprieves from alerts, however, reset these costs.

[4] Station distance itself is differenced away in the within transformation because it is time invariant.

$$q_{it} = \beta_{8,1} STA_t + \beta_{8,2} FREE_t + \beta_{8,3} STA * DIST_i^{transit} + \boldsymbol{\delta}\mathbf{Z_t} + \boldsymbol{\gamma}\mathbf{D_t} + \xi q_{it-1} + \theta_{it} + \mu_{it}, \quad (8)$$

and

$$q_{it} = \beta_{9,1} STA_t + \beta_{9,2} FREE_t + \beta_{9,3} STA * DIST_i^{CBD} + \boldsymbol{\delta}\mathbf{Z_t} + \boldsymbol{\gamma}\mathbf{D_t} + \xi q_{it-1} + \theta_{it} + \mu_{it}. \quad (9)$$

The coefficients on $STA * DIST_i^{transit}$ and $STA * DIST_i^{CBD}$, $\beta_{8,2}$ and $\beta_{9,2}$, respectively, are interpreted as the marginal effect of distance on STA effects on traffic volume. They are positive if STA cooperation is decreasing in distance from the downtown and transit alternatives. Distance is measured in meters.

Equations 5-9 are estimated principally by use of the RDD. In the RDD, the econometrician faces a tradeoff in specifying the width of bands about the treatment threshold of the predictor variable. A narrower band weakens the assumption of smoothness in the conditional distribution of the dependent variable about the threshold, i.e. it makes such an assumption more defensible. But a small bandwidth sacrifices sample size and diminishes the asymptotic efficiency of the estimators. Consequently, two bandwidth specifications are used. The first includes observations within 20 parts per billion (ppb) of the ozone threshold used to determine STA status. The second includes observations within 10ppb of the administrative threshold.[5] These are the same bandwidths specified in C-N. Equations 5 and 6 are also estimated separately using hourly traffic volumes in order to determine whether cooperation is greater for discretionary trips, than work-related trips.

To measure changes in car trips (i.e., traffic volumes), this paper employs unique data on traffic volumes measured at various points along Bay Area freeways. These data are generated using a network of vehicle detectors embedded in the roadway. The network is managed by the California Department of Transportation, in conjunction with the UC Berkeley Department of Electrical Engineering and Computer Science. It includes 11,716 stations throughout the state. This paper uses 1,275 stations in the Bay Area that offer multiple observations on traffic volume across all lanes of traffic along each major highway segment. The network generates reports with traffic counts for each station every five minutes. Five-minute reports are aggregated to hourly and daily reports, which are used in this analysis. Because stations were installed at different times and are subject to malfunction, the number of observations varies by station, yielding an unbalanced panel.[6] We assume that these station errors are uncorrelated with STA and therefore do not bias the estimation. These same reports provide traffic counts separately for each lane. Observations on HOV lane volumes are derived from these reports by identifying stations located along HOV-lane segments and referencing traffic counts for lane 1, which identifies the HOV lane if an HOV lane exists. Data on transit ridership are obtained from entry and exit data provided by BART pursuant to a public records request.

Data on STAs and ozone forecasts were obtained from the Bay Area Air Quality Management District (BAAQMD). We observe 57 STA days and 12 STA free fare days. Following

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[5] The U.S. EPA changed the correspondence between AQI and ozone concentration in 2008. Hence, the wide bandwidth corresponds to AQI between 51 and 151 before 2008 and between 47 and 151 after 2008. The narrow bandwidth corresponds to AQI of 77-127 before 2008 and 71-127 after 2008.

[6] For a thorough description of these data and the Freeway Performance Management System, see Chen [2003].

Table 1: Summary Statistics: Number of STA days by year

		All	Wide	Narrow
Year	STA=1	STA=0	STA=0	STA=0
2002	8	153	32	4
2003	9	153	65	13
2004	4	153	32	5
2005	1	153	49	6
2006	11	153	53	10
2007	2	153	27	7
2008	12	153	85	19
2009	10	153	58	14
Total	57	1,224	401	78

the BAAQMD's administrative decision rule for issuing STAs, we use the maximum forecasted AQI across BAAQMD regions. The STA season initially ran from June through October, though it has since been extended to May. We consider observations during the more restrictive STA season from 2002-2009. Data on contemporaneous weather-related variables (i.e. high and low temperatures and precipitation) were obtained from the Surface Summary of the Day provided by the National Climatic Data Center. GIS software was used to assign observations from eight Bay Area weather stations to traffic stations according to proximity between weather and traffic stations. Forecasted high and low temperatures and sky conditions were obtained from the NCDC's coded city forecasts. Forecasts from four Bay Area weather stations that issue such reports are assigned to traffic stations in the same manner as contemporaneous weather variables. Distance variables were obtained for each station using spatial mapping software and an "as the crow flies" distance metric.

Summary statistics are reported in tables 1-3. Table 3 demonstrates that the covariates are relatively well balanced across RDD bandwidth specification.

5 Results

5.1 Aggregate STA Effect

STA has a statistically significant effect on vehicle traffic under all specifications of equation 1, including random and fixed effects assumptions and under the regression doscontinuity design with narrow and wide bands. These results are reported in Table 4. Based on preferred fixed-effects estimates with the RDD design, STA causes car trips to decline along monitored freeway segments by 781-904 trips. This corresponds to a 1.15-1.33% decline in traffic volumes based on preferred estimates. STA has a significant effect on BART trips in only some specifications. The fixed-effect RDD estimation that uses wide bands generates a statistically significant estimate that STA increases BART ridership by 118 trips. This corresponds to a 1.78% increase in BART ridership. The RDD with narrow bands is insignificant at any level. The unrestricted linear estimation generates a statistically significant estimate that STA boosts transit ridership 1.39%. These results are roughly consistent with those of C-N, which found a 3% reduction in traffic volumes and a 0.7%

Table 2: Summary Statistics: Means of dependent variables by hour

Traffic						
Hour	Mean	Std. Dev		Hour	Mean	Std. Dev
12am	1104.14	685.099		12pm	3746.153	1677.16
1	829.8242	565.3937		13	3817.438	1705.131
2	741.4134	536.587		14	4024.01	1805.522
3	705.0397	502.1937		15	4197.345	1879.556
4	921.9522	614.3089		16	4276.889	1908.96
5	1747.914	1274.173		17	4333.348	1930.179
6	2818.499	1902.991		18	4003.902	1815.604
7	3580.517	2143.15		19	3389.14	1588.042
8	3685.555	1951.651		20	2830.729	1350.566
9	3614.698	1726.576		21	2587.56	1268.425
10	3556.069	1616.14		22	2185.301	1155.18
11	3636.838	1641.644		23	1594.334	918.5544
All day	68052.61	29265.68				

BART		
	Mean	Std. Dev
All day	6491.992	6566.547

Table 3: Summary Statistics: Means of dependant variables and covariates

	All Observations	RDD Wide	Narrow
Traffic Volume	68052.61 [29265.68]	67867.46 [29416.87]	67680.13 [29621.65]
BART Volume	6491.99 [6566.55]	6610.63 [6688.46]	6661.73 [6770.96]
Precipitation	0.07 [0.67]	0.01 [0.22]	0.003 [0.15]
Max. Temp.	76.62 [10.00]	81.59 [10.98]	87.11 [11.37]
Min. Temp.	55.25 [4.23]	56.02 [4.57]	58.06 [4.53]
Forecast High	71.38 [13.60]	75.25 [15.07]	78.40 [15.97]
Forecast Low	61.48 [11.98]	62.82 [12.67]	65.12 [13.94]
Forecast Clear	0.55 [0.50]	0.66 [0.48]	0.70 [0.46]
Forecast Cloudy	0.42 [0.49]	0.32 [0.47]	0.27 [0.44]
Forecast Rainy	0.02 [0.14]	0.01 [0.10]	.002 [0.05]
Day of Week	3.00 [2.00]	2.89 [1.98]	3.05 [2.00]
Month	8.04 [1.39]	8.23 [1.30]	7.74 [1.14]
Year	2005.03 [2.18]	2005.27 [2.27]	2005.49 [2.39]

NOTE: Std. Dev in brackets.

Table 4: STA Effect on All Day Traffic and BART Ridership

VARIABLES	(1) All Observations	(2) RDD Wide	(3) RDD Narrow
Traffic			
STA Day FE	-472.5***	-904.0***	-781.3***
	(35.76)	(46.63)	(75.37)
STA Day RE	-456.1***	-850.6***	-673.4***
	(55.00)	(66.56)	(104.6)
Observations	1222343	438024	122101
Mean No. of days	958.7	343.5	95.9
BART			
STA Day FE	90.54***	117.9***	39.57
	(24.85)	(36.55)	(54.71)
STA Day RE	2.300	-3.711	-125.7
	(86.28)	(108.1)	(181.1)
Observations	42530	15406	4522
Mean No. of Days	1012.6	366.8	107.7

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

increase in BART ridership. Our results likely differ because of two important differences in the data. First, this analysis draws on traffic volume observations from all 1,275 monitors in the Bay Area, whereas C-N randomly selected 40 monitors that cover all major freeway segments.[7] Second, C-N used data from 2001 to 2004, which included free fares in only the last year of the sample. They did not account for the partial effect of free fares on traffic volumes. The data in this paper cover 2002-2009 and include four years of free fare STA days. As is shown in the subsequent subsection, free fares boost BART ridership *and* traffic volumes, which can explain why the aggregate car-trip-reduction effect reported in Table 4 is smaller than that reported by C-N and why the effect on BART ridership is larger. When we restrict attention to the period 2002-2004, we obtain a statistically significant estimate that STA reduces car trips by 2.29%, which is closer to the estimate of C-N.

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[7] C-N do not report which stations are used in the analysis.

5.2 Pecuniary effects versus cooperation

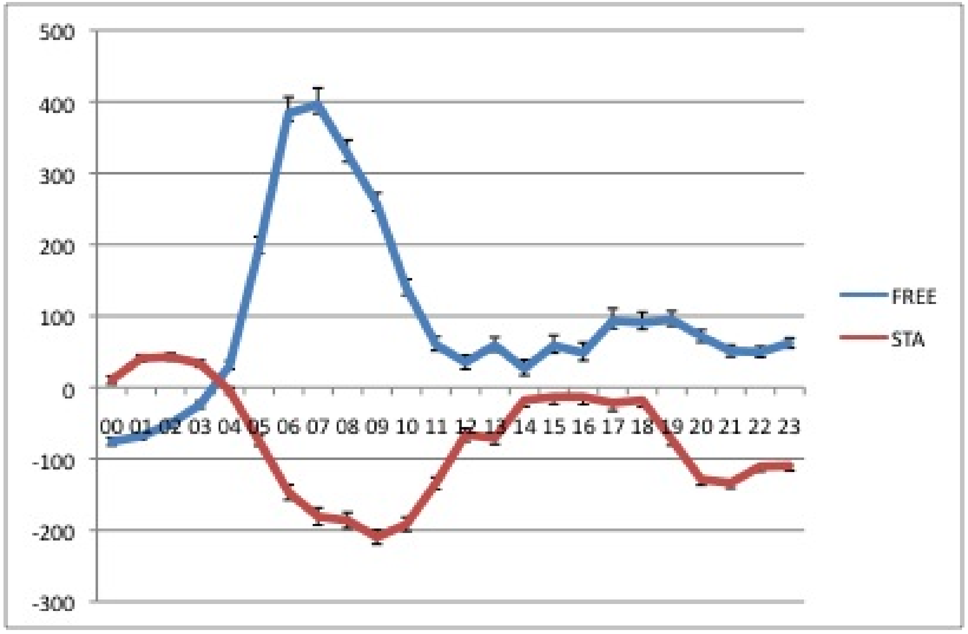
The first major innovation of this paper is to separately estimate the effect of the appeal for cooperation associated with STA days and the free transit fares attached to some STA days. These effects were estimated by (6) and are reported in Table 5. As before, we find statistically significant effects of STA on traffic volumes in all specifications. The effect of free transit fares (FREE) is also statistically significant in all specifications. Somewhat surprisingly, the free fare effect is positive, meaning that the offer of free transit rides induces more car trips. By disaggregating the two elements of the STA treatment, namely the appeal for cooperation and the pecuniary incentive, we find that, under our preferred specifications, STA (appeals) reduce car trips by 1660-1674 trips on monitored highways, or roughly 2.5%. Free Fare, however, induces between 3,070 and 3769 additional trips–a 4.52-5.55% increase in car trips. In considering the marginal effects on BART ridership, we find statistically significant effects for both STA and FREE under the fixed effects specification only in the RDD with narrow bands. The STA effect is significant at the 95% level while FREE is significant at the 99% level. In fact, FREE is significant in all specifications at the 99% level. Under the RDD with narrow bands and fixed-effects, we find that STA reduces BART trips by 148, while FREE causes 594.7 more trips. These results suggest that appeals for reduced car trips induce 2.22% fewer transit trips. Free fares, however, increase BART trips 8.92%.

These results seem surprising at first because free fares should induce a substitution from car trip to transit trip and because STA (as distinct from STA and FREE) should activate intrinsic motivations that cause an increase in transit trips. However, mindful that congestion and salience of poor air quality can lower utility from transit trips on STA days, it is entirely possible that, for some people, the cooperation effect is dominated by these other concerns on STA days. Free fares may induce new transit trips among segments of the population with particularly elastic demands. Together, the effects of STA and FREE on car and BART trips suggests that regular transit riders are dissuaded from riding transit on STA days either because of fears of crowding or because of the heightened salience of low air quality and risks of exposure. However, these travelers are more than supplanted by discretionary transit travel that would not have occurred without the free fare. This travel contributes nothing to the goals of the STA program.

Fears of crowding can be expected to be greater on days when free fares are offered, which could induce greater shares of regular transit riders to substitute to alternative trip modes, like car trips. This explains the statistically and economically significant increase in traffic volumes on free fare days. The contemporaneous increase in car trips and BART trips on free fare days also supports the theory that free fares predominantly subsidize new BART trips that partially displace regular BART trips that are instead made by car. The fact that FREE increases car trips also supports theories that suggest intrinsic motivations may be crowded out by extrinsic motivations. It is entirely possible that the small pecuniary incentives for substitution to transit are insufficient to cause such a substitution among a sizeable share of motorists, but that they are sufficient to deactivate altruism. It is impossible to determine from these data to what extent these various explanations are responsible for the increase in car trips on STA days. Nevertheless, based on this analysis, it is evident free fares have not generated the intended effect of reducing car trips on high-smog days.

Figure 1 shows point estimates and 95% confidence intervals derived from the separate estimation of Equation 6 for each hour of the day using traffic volume data and the RDD-

Figure 1: STA and FREE Effects on Traffic Volume by Time of Day



NOTE: Point estimates with 95% confidence intervals

wide specification. As in C-N, the STA-induced trip reduction is greatest during the morning commute and after the evening commute. STA causes a statistically significant increase in traffic volume before 4AM, but otherwise causes at least modest car trip reductions.[8] FREE is shown to have a highly significant and positive effect during the morning commute that dominates the STA effect. After 4AM, the effect of FREE is everywhere positive and significant, though the magnitude of the FREE-induced increase in car trips is relatively small after 11AM. C-N interpret the dynamics of STA effects to suggest greater responsiveness in discretionary than commute trips. This explains, for instance, the large decline in car trips after the evening commute. C-N interpret relatively large reductions in traffic volumes during the morning commute but no matching reductions during the evening commute as further evidence that much of the response to STA is derived from discretionary trip reduction. They admit the small magnitude of effects exhibited during the evening commute could reflect smoothing of the evening commute. This interpretation, however, is difficult to reconcile with evidence that FREE effects are largest during the morning commute as well. If discretionary car travel is likely to decline because of an appeal for cooperation, then it should not increase when free public transportation is offered in conjunction with the public appeal, unless discretionary car trips are avoided by substitution to transit and FREE induces fears of crowding and delays that reverse the substition effect. It is clear that morning trips are most responsive to STA and FREE and that the two treatments are strongly negatively correlated.

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[8] C-N do not report results before 5AM.

Table 5: STA Free Effects

VARIABLES	(1) All Observations	(2) RDD Wide	(3) RDD Narrow
Traffic			
STA Day FE	-1086***	-1660***	-1674***
	(41.92)	(53.24)	(77.69)
Free Fare FE	2796***	3070***	3769***
	(71.53)	(77.42)	(93.85)
STA Day RE	-1019***	-1532***	-1494***
	(59.99)	(71.50)	(108.4)
Free Fare RE	2573***	2766.79***	3403***
	(86.11)	(89.03)	(114.8)
Observations	1222343	438024	122101
Mean No. of days	958.7	343.5	95.9
BART			
STA Day FE	-6.696	16.15	-148.2**
	(19.44)	(34.02)	(67.86)
Free Fare FE	379.3***	341.7***	594.7***
	(69.12)	(67.81)	(120.0)
STA Day RE	-146.7	-190.9*	-388.3**
	(91.24)	(115.1)	(191.5)
Free Fare RE	582.1***	630.9***	833.9***
	(166.2)	(171.9)	(215.7)
Observations	42530	15406	4522
Mean No. of Days	1012.6	366.8	107.7

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.3 STA Fatigue

We find strong evidence that responses to STA and FREE are diminished on successive days. Table 6 shows that people are less likely to cooperate on the second or more consecutive STA day, suggesting that the costs of cooperation increase when multiple STA days are issued consecutively. The effect of consecutive days is estimated as a marginal effect on the average STA effect as per (7). The estimated effect of consecutive STA days on car trips is highly significant in all specifications (which use FE) and is of an equal magnitude to the average STA non-consecutive effect. This means that the effect of STA is nearly fully lost on consecutive days. The effect of FREE is also highly significant and of the opposite sign as the main effect, suggesting also that responsiveness to free fares is diminished on consecutive free fare days. The magnitude of the marginal effect of consecutive free fare days varies by specification, from roughly 10% to 30% of the main effect.

For BART, the marginal effects of consecutive STA and FREE days are highly statistically significant in all specifications. The marginal effect of consecutive STA days increases BART ridership relative to the average effect of STA. The increase in ridership on consecutive days dominates the decline in ridership due to the average STA effect. This suggests that BART riders may substitute away from transit on an initial STA day because of health concerns or fear of crowding, but that the costs of transit avoidance on subsequent days are too high to induce substitution. Regular transit riders return to transit on consecutive STA days. A consecutive day of free fares reduces the FREE-induced increase in ridership by roughly 50% across all specifications. Because a commuter induced to ride BART because of free fares on the first free fare day in a series of free fares should similarly be induced to ride BART on a consecutive day, these results suggest that up to 50% of the increase in BART ridership is due to additional trips that are not part of regular commute trips. Free fares induce some people to make a trip on an STA day, but conditional on having made the trip the day before, most do not demand an additional free fare trip on a consecutive FREE day.

We find strong evidence in support of an STA and FREE fatigue hypothesis wherein travelers are less responsive to public appeals and pecuniary incentives if they have been exposed to such treatments the day before. This finding is consistent with Zivin and Niedell (2009), who find health-risk-avoidance behavior declines in response to consecutive smog alerts in Los Angeles. These results suggest that if air quality regulators forecast high ozone levels for a number of days in a row, they should target treatments for the day or days expected to have the lowest air quality, rather than issuing STA alerts on all days forecasted to exceed the AQI threshold.

5.4 Cooperation and Distance

Utility maximizing agents weigh the net benefits associated with mode choice. In order for such an agent to cooperate and avoid car trips, the benefits of cooperation, inclusive of intrinsic rewards, must exceed the costs, which, as previously discussed, include heightened exposure to air pollution and congestion. Substitution from car trips to transit may also be associated with a time penalty as the transit trip may be of greater duration than the equivalent car trip. Travelers may also exhibit preferences for travel in private rather than in public, which means transit is also associated with a “comfort” penalty. The time penalty is hypothesized to increase in distance from a transit station. The time penalty is also

Table 6: Effects of consecutive STA Days

VARIABLES	(1) All	(2) RDD Wide	(3) RDDNarrow
		Traffic	
STA	-1785***	-2203***	-1981***
	(54.69)	(61.32)	(82.71)
STA Consec	1813***	1746***	2868***
	(83.01)	(89.81)	(94.33)
Free	3740***	3965***	4877***
	(89.81)	(94.16)	(116.2)
Free Consec	-3165***	-3122***	-4486***
	(139.0)	(140.6)	(155.4)
Observations	1222343	438024	122101
		BART	
STA	-118.8***	-76.79*	-181.3**
	(32.30)	(39.23)	(72.74)
STA Consec	286.5***	280.8***	443.5***
	(56.51)	(53.79)	(82.06)
Free	669.5***	609.3***	781.6***
	(109.0)	(107.4)	(155.5)
Free Consec	-886.5***	-840.4***	-778.8***
	(145.6)	(150.1)	(156.3)
Observations	42530	15406	4522
Number of station	42	42	42

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

hypothesized to increase in distance from the CBD. Because the time penalty increases in distance from the CBD, so too is the comfort penalty presumed to increase in distance from the CBD because the discomfort associated with public travel is experienced for a longer period of time. Consequently, the costs associated with cooperation are higher the farther is an agent from a transit station and the CBD.

This intuition predicts that traffic volumes at monitors farther from transit stations will experience less responsiveness to STA as will those farther from the CBD. Likewise, BART stations that are farther from the CBD should also experience less responsiveness to the STA. The responsiveness of traffic volumes and transit ridership to FREE is less clear. If the fares associated with transit rides increase more than proportional to the time and comfort penalties, then FREE should induce greater response rates at more remote locations. However, we expect the time and comfort penalties increase more or less proportional to distance and that, allowing for some price discrimination, BART fares increase less than proportionately to distance.

Distances from each traffic monitor to the CBD and the nearest BART, bus, and train stations were computed using locational data from the Bay Area's Metropolitan Transportation Commission and spatial analysis software with a "as the crow flies" distance metric. Results from estimation of (8) and (9) are reported in Table 7, where we separately estimate the effect of distance on aggregate STA response and the distinct responses due to STA and FREE. In the first case, cooperation on STA *increases* by 5 car trips per 1 kilometer of distance from a train station. This estimated effect is statistically significant at the 95% level. Distance to the CBD and to the nearest BART station are also statistically significant at the 90% level, with cooperation increasing by 3 car trips per 1 kilometer from the CBD and by 4 car trips per kilometer from the nearest BART station. Distance to bus stops is insignificant. Distance has a statistically significant effect (at the 95% level) on STA day BART ridership. Cooperation via BART ridership declines by 20 trips per kilometer from the CBD, which is consistent with costs of cooperation rising more than proportional to distance. Similarly, the response to free fares declines with distance to the CBD by 30 BART trips per kilometer from the CBD. These results suggest that, contrary to a hypothesis of diminished car trip avoidance at distances farther from transit, cooperation increases with distance to transit. STA and FREE-induced BART ridership, however, diminished with distance to the CBD, which is consistent with the costs of substitution to public transit increasing with the duration of the transit ride.[9]

5.5 Do people carpool more on STA Days?

The STA program appeals to motorists to reduce car trips by either avoiding trips, substituting to transit or carpooling. The traffic monitor data used throughout this analysis permits analysis of STA-related changes in carpooling behavior. The number of carpools should increase in response to the public appeal for cooperation as motorists who typically do not carpool respond to intrinsic motivation by carpooling on STA days. The number of carpools may decline on STA days if those who regularly carpool opt to avoid a trip or use transit instead. Because carpooling is considered one of the prosocial behaviors the STA

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[9] Though the distance analysis presented in Section 5.4 does not control for spatial heterogeneity in terms of demographics, one expects that to the extent income is increasing in distance to public transit, the lack of demographic controls in the spatial analysis imposes a downward bias in the estimation of distance effects.

Table 7: Distance Effects on Cooperation

VARIABLES	(1) To SF	(2) To BART	(3) To Bus Stop	(4) To Train
Traffic: STA Day Effects				
STA Day	-796.3***	-857.7***	-913.3***	-824.4***
	(79.77)	(55.28)	(55.43)	(59.11)
Distance	-0.00307*	-0.00471*	0.0129	-0.00523**
	(0.00177)	(0.00271)	(0.0376)	(0.00217)
Traffic: STA Day and Free Fare Effects				
STA Day	-1539***	-1708***	-1764***	-1716***
	(92.32)	(65.11)	(61.87)	(65.81)
STA Day X Dist.	-0.00359*	0.00420	0.145***	0.00382
	(0.00212)	(0.00337)	(0.0405)	(0.00238)
Free Fare	3497***	3689***	3546***	3568***
	(192.2)	(112.8)	(106.6)	(123.6)
Free Fare X Dist.	-0.0114**	-0.0580***	-0.667***	-0.0339***
	(0.00475)	(0.00717)	(0.0923)	(0.00651)
BART: STA Day Effects				
STA Day	600.2***			
	(201.0)			
Distance	-0.0255**			
	(0.0101)			
BART: STA Day and Free Fare Effects				
STA Day	343.6**			
	(141.1)			
STA Day X Dist.	-0.0162**			
	(0.00672)			
Free Fare	986.1***			
	(287.1)			
Free Fare X Dist.	-0.0383**			
	(0.0150)			

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

program is intended to induce, we expect such substitutions to public transit to be unlikely. Free fares, however, may induce regular carpoolers to substitute to transit, causing a decline in carpooling on FREE days. Regular transit riders, worried about crowding, however, may substitute to carpooling in order to avoid the transit congestion and still provide prosocial behavior.

In order to test the magnitude of STA and FREE effects on carpooling, the subset of traffic monitors located along HOV segments was identified. For a traffic monitor located within an HOV segment, it is known that lane 1 is the HOV lane and that other lanes within the Bay Area are "mainline" or unregulated lanes. Within the Bay Area, HOV lanes are actuated during morning and evening commute hours when traffic congestion is a problem.[10] During these periods of actuation, only those vehicles that carry the minimum number of passengers (typically two in the Bay Area, but three along some segments) may lawfully travel in the HOV lane. Vehicles that travel in the HOV lane with fewer passengers are subject to fines in excess of \$300. When these segments are free flowing, i.e. there is no congestion, HOVs may travel in any of the lanes. However, when the HOV lanes are actuated and congestion is a problem, the HOV lane offers an advantage relative to other lanes because it is less congested due to the minimum passenger requirement. Therefore, it is assumed that traffic volumes recorded by monitors located along HOV segments during actuation and congestion offer a reasonably accurate count of HOVs. So long as cheating (i.e. travelling in HOV lanes with fewer than the minimum number of passengers) and other factors affecting HOV lane traffic volumes are uncorrelated with STA, these traffic counts can be used to identify the STA-induced change in carpool behavior. Based on these characteristics of HOV lane access, we can identify whether STA has a differential effect on carpooling relative to car trips generally. STA is expected to have a non-positive effect on traffic volumes in general, but the program is intended to have a positive effect on carpooling.

In order to determine if there is a differential effect, (6) is estimated using hourly traffic volumes for lane 1 (the HOV lane), and lane 2 (the adjacent lane). During periods when the HOV lanes are not actuated and when traffic is free flowing, the effect of STA (and FREE) should be similar across these two lanes. When the HOV lanes are actuated and when there is traffic congestion, however, STA should have a differential effect on traffic volumes in these two lanes. The 95% confidence intervals for each of these hourly regressions on lane 1 and lane 2 traffic volumes are depicted in Figure 2. The STA effects seem to covary across the two lanes until rush hour and HOV lane actuation begins at around 6AM. Before 6AM, the 95% confidence interval for lane 2 was higher than the 95% confidence interval for lane 1. But from 6AM to 10AM, the lane 1 confidence interval lies above the lane 2 confidence interval. Furthermore, the change in estimated coefficient from hour to hour deviates from the covariation observed before 6AM. This pattern persists through the evening commute, as well. During periods of congestion and HOV actuation, the effect of STA on traffic volumes in the carpool lane is always non-negative and typically positive and significant at the 95% level. In contrast, the effect of STA on lane 2 traffic volumes is non-positive during the relevant time periods, or at least dominated by the STA effect on carpools. A test of statistical difference between the estimated effects of STA on carpool lane and mainline traffic during carpool actuation periods rejects the null hypothesis of no difference in each hourly interval at the 99% level.

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[10] Exact times vary by HOV segment, but are typically between 6-10AM and 3:30-7PM.

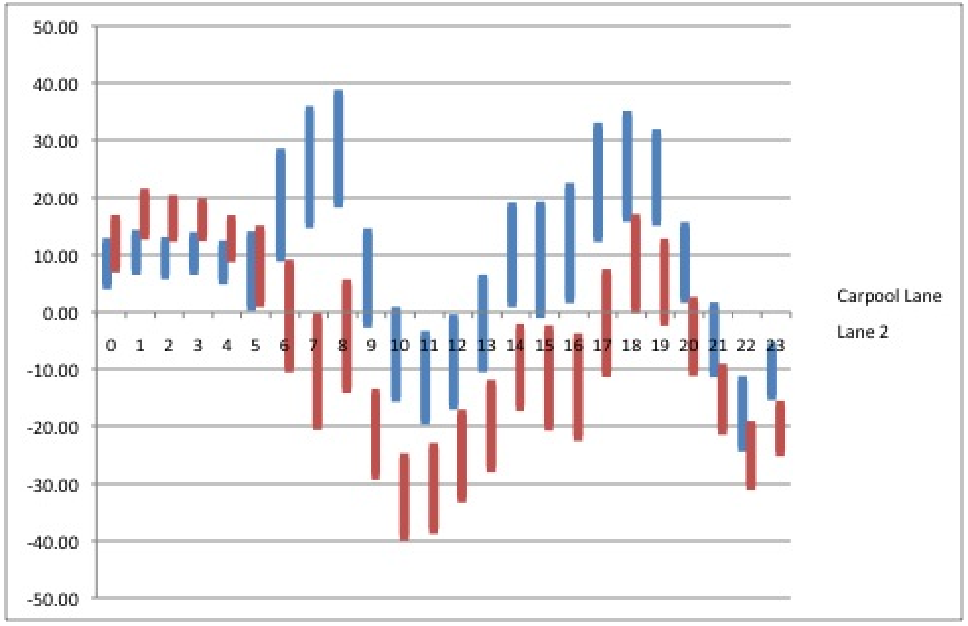
This analysis can be refined by identifying those HOV lane segments that are actuated at each hour rather than just identifying HOV segments. In other words, we can exclude HOV segments that are not actuated in a given hour due to variation in actuation periods. This necessarily restricts attention to the periods of actuation. The results of these estimations are shown in Figure 3. STA has a statistically significant and positive effect on carpooling during all periods of HOV lane actuation except 3-4PM and 7-8PM. In contrast, STA generally has an insignificant effect or a significant and negative effect on traffic volumes in lane 2. In only two cases, at 5AM and 6PM does STA have a statistically significant and positive effect on traffic volumes in lane 2. At 6PM, the magnitude of this effect is dwarfed by the effect on carpool lane traffic volumes. The estimated STA effects are also statistically different.

Together, Figures 2 and 3 provide convincing evidence that motorists respond to appeals for car trip reductions by carpooling. Table 8 reports the effect of STA on lane 1 traffic volumes in each period of actuation as a percent of mean lane 1 traffic volumes in each period where the estimated effect is statistically significant at the 90% level or higher. It likewise reports the percentage effect of STA on lane 2 traffic volumes. Throughout the actuation period, STA increases carpooling by 0.65-3.65%. In contrast, it reduces mainline traffic by 0.07-2.74%. This analysis relies on the ability to sort carpoolers and mainline traffic. Consequently, it is contingent on carpoolers self-selecting into HOV lanes to benefit from travel-time savings and mainline traffic self-selecting out of HOV lanes to avoid hefty fines associated with violating minimum passenger requirements for actuated HOV lanes. Note, however, that the identification of the STA effect on carpooling does not require that all cars in HOV lanes comply with the law regulating minimum passengers. It is sufficient that the number of cheaters in HOV lanes does not correlate with STA days. Nevertheless, we have not estimated STA-induced changes in carpooling behavior outside the actuation period because the sorting on which we rely is not feasible outside this period. If one expects carpooling response to STA to vary throughout the day, then one cannot extrapolate from this analysis to a daily change in carpooling behavior. One can consider that time savings associated with carpooling during actuation periods may reduce the costs associated with heeding calls for cooperation. Thus, we may expect the carpooling response to STA days to be greater during the actuation periods than the rest of the day. This would cause an out of sample extrapolation of daily average carpool response to STA to be biased upwards.

6 Discussion and conclusions

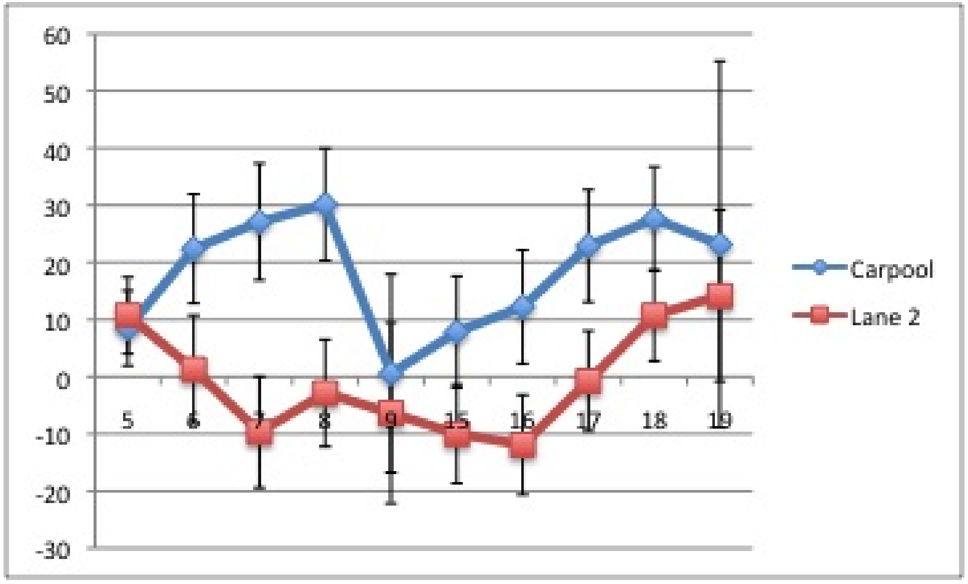
Previous studies have undertaken to estimate the responsiveness of motorists to episodic appeals for car trip reductions (Cummings and Walker 2000, Lu et al. 2004, Schreffler 2003, Welch et al. 2005). This is the first analysis to separately estimate responsiveness to public appeals for cooperation and pecuniary incentives, which form a dual treatment in some such programs across the country, including the STA program in San Francisco. By estimating these effects separately, we find that, surprisingly, the STA effect increases dramatically in magnitude because free fares induce additional car trips, rather than substitution away from cars trips to free transit rides. Public appeals for car trip avoidance are estimated to reduce car trips by 2.5% on average, whereas free fares on STA days are estimated to increase car trips by 4.5-5.5%, enough to swamp the cooperation exhibited in response to the STA appeal.

Figure 2: Comparison of STA effects along HOV segments



NOTE: 95% Confidence Intervals for HOV segments (Blue=Lane 1, Red=Lane 2)

Figure 3: Time specific Carpool Effects



NOTE: Point estimates with 95% confidence intervals

Table 8: Percent change in carpool and mainline traffic due to STA (by time-of-day)

Time	Carpool	Lane 2
6	3.13	-0.07
7	3.30	-0.84
8	3.65	-0.34
9	0.65	-1.78
10	-0.80	-2.74
15	0.91	-0.80
16	1.17	-0.92
17	2.19	-0.13
18	2.65	0.64
19	2.71	0.48

Equally surprising are the effects of STA appeals and free fares on public transit ridership as exhibited by BART ridership. In particular, BART ridership declines by 2.2% on days with STA appeals and no free fares. On free-fare STA days, however, transit ridership climbs nearly 9%. Because STA appeals urge substitution to transit as a way to reduce car trips, a decline in transit ridership in response to such appeals is surprising. The BART findings suggest that while some motorists may substitute to BART in response to STA appeals, a greater number of regular BART commuters avoid BART on STA days. This is likely because of fears of crowding and delays. The net increase in ridership on free fare days suggests either that regular commuters who avoid BART on regular STA days can be induced to suffer disutility from crowding if compensated by a free fare or that there are sufficient new trips to generate a sizeable net increase in ridership even with a fraction of regular BART commuters staying away. If one considers the findings from BART ridership and traffic volumes together, there is evidence that free fares produce more car trips, which would be consistent with an interpretation of regular transit riders substituting to car trips on free fare days. These findings are also consistent with behavioral theories that altruistic behavior is diminished when intrinsic motivations interact with extrinsic motivations, such as rewards, punishments, and pecuniary incentives.

There is considerable cost associated with free-fare STA days because transportation and pollution control dollars are required to reimburse transit agencies for the costs of foregone fairs. These costs are estimated at $2-2.5 million per free-fare STA day. If there were net reductions in car trips associated with free fares, it would be appropriate to carry out cost-benefit analysis to determine whether free-fare STA days are an optimal use of scarce funds. Given that this analysis finds that free fares have the opposite effect intended by regulators–that they actually increase car trips–it is evident that the BAAQMD and other regulatory bodies should cease free-transit programs associated with episodic pollution control. Indeed, BAAQMD halted the free-fare program in 2008. Other programs continue to offer free fares, however. Absent fare reimbursement costs, the STA program imposes only a small burden on budgets–largely for expenses related to administering the program and some marketing expenditures. Therefore, STA appeals likely represent a low-cost mechanism for episodic pollution control even if it yields only a 2.5% reduction in car trips.

The second major finding of this analysis is that consumers respond to appeals for car trip avoidance by carpooling. Because carpooling is one of the suggested ways of reducing car trips, we would expect to find evidence that carpooling increases on STA days. Indeed, based on analysis of traffic volumes along HOV segments during HOV lane actuation and congestion, we find a generally significant increase in carpooling of 2.19-3.65%. The differential effect of STA on carpooling and mainline (non-carpool) traffic is statistically significant. C-N did not estimate the effect of STA on carpooling, which is one of the prosocial behaviors the program is intended to elicit. One would not expect motorists to undertake the potentially significant upfront costs associated with establishing carpool networks in response to an episodic appeal for trip reductions. Therefore, this analysis suggests that a fraction of the driving public can, at relatively low cost, substitute from single-passenger vehicles to multiple-passenger vehicles and on relatively short notice. With small inducements, then, such motorists could be motivated to make a quasi-permanent switch to carpooling.

Finally, consistent with findings in the health-risk avoidance literature, we find that responsiveness to STA appeals and free fares drops off considerably on consecutive STA days. In fact, the marginal effect of an STA day or free-fare day being preceded by an STA day or free-fare day, respectively, is of the opposite sign and the same magnitude as the main effect. This means that there is nearly no response to consecutive treatments. Therefore, regulators should use caution in making such public appeals and instituting free-fare days because fatigue develops quickly. These instruments of ozone-emissions reductions should be saved for the most severe days or the days when they can most effectively achieve air quality goals.

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