

Draft Version

**Congestion Pricing
and Motor Vehicle Emissions:**

An Initial Review

**Randall Guensler
Daniel Sperling**

Reprinted from the Proceedings of the TRB/CBASSE

Congestion Pricing Symposium

June 1993

Draft Version

This version of the paper includes revisions to tables and text subsequent to the 1993 symposium. However, this version does not include the changes made by TRB editorial staff. Hence, this document is still a draft version and should be discarded once the TRB/CBASSE Congestion Pricing Symposium Proceedings are available.

**Institute of Transportation Studies
University of California, Davis
Davis, California 95616
Tel. 916/752-6548 Fax 916/752-6572**

1950

1951

1952

1953

1954

1955

1956

1957

ABSTRACT

An exploratory analysis of four congestion pricing scenarios is conducted. Using projected changes in vehicle operating conditions from the literature, percent changes in emission rates are estimated for the four scenarios. A range of emission impact estimates are provided, based upon confidence intervals associated with the existing modeled relationships between average vehicle speed and emissions. The high degree of uncertainty in emission estimates is evidenced by the large range of empirical results. The actual uncertainty in emission impact estimates is even greater than indicated by the ranges provided in this paper, due to the innumerable sources of emission calculation uncertainty that are discussed in recent emission inventory uncertainty literature.

The results of the impact assessment indicate that our ability to estimate the emission impacts of congestion pricing are questionable at best. However, based upon our knowledge of the cause effect relationships at work, we can make a few qualitative conclusions with some degree of confidence: 1) where congestion pricing causes automobile vehicle trips and vehicle miles of travel to decline, emission benefits for all pollutants will accrue, to the extent that they are not offset by increased emissions from alternative modes; 2) where congestion pricing reduces congestion and smoothes traffic flow, emission rates per mile of travel will likely decline for carbon monoxide and hydrocarbons, but will likely increase for oxides of nitrogen; 3) if congestion pricing yields increased vehicle activity at high speeds, in excess of 55 mph, emission increases are likely for all pollutants; and 4) where congestion pricing increases congestion and lowers average operating speeds on local roads, emission rates per mile of travel will likely increase for all pollutants.

In practice, the net effects of congestion pricing on traffic flow are likely to be limited to the areas surrounding those freeway links that are currently severely congested or expected to be

congested in the future (i.e. mitigating future congestion increases). Hence, emission impacts are localized and limited to the VMT occurring during peak periods at these locations.

INTRODUCTION

Traffic congestion is now widespread on freeways and arterials in most urban areas. The Federal Highway Administration estimates that more than 65 percent of the urban freeways are congested during peak periods, creating more than 2 billion vehicle-hours of delay, and user costs in excess of \$15.9 billion per year (GAO 1991). Congestion levels are also rising, meaning that the delay, energy, and air quality impacts of congestion continue to worsen.

Because there has recently been increased regulatory focus upon implementing economic incentives in the environmental arena (USEPA 1992a; Guensler 1992; Ketcham 1991; Regulatory Flexibility Group 1991; South Coast Air Quality Management District 1991; Hahn and Stavins 1990), it is natural that congestion pricing would be explored as a means to achieve transportation behavioral changes in the urbanized areas with the worst air quality.

Congestion pricing has the potential to fundamentally change tripmaking behavior, yielding changes in the number of trips, types of trips, trip length, mode choice, etc. In theory, congestion pricing will increase the efficiency and capacity of the existing highway system by reducing the use of vehicles during peak periods. Emission reductions would be associated with the actual reduction in vehicle activity, as well as the change in vehicle operating conditions on the roadway. As traffic congestion is reduced and operating conditions move closer to free flow, traffic flows are smoothed and emission rates per mile of travel are expected to decrease.

Until a few years ago, analysts had sufficient confidence in existing emission models of the US Environmental Protection Agency and the California Air Resources Board to generate quantitative answers to congestion pricing impact questions. Indeed, given postulated changes in vehicle activity from congestion pricing scenarios, any number of consulting firms would be more than willing to employ the existing emission modeling regime to prepare an analysis of congestion pricing emission impacts. However, the most recent literature in both the vehicle activity and emission rate modeling research indicates that many of the problems associated with using the existing modeling regime for impact analyses of this type are insuperable. We will keep these factors in mind in our analyses and interpretation of empirical findings.

Accurate quantitative estimates of congestion pricing impacts on air quality are not possible at this time because a number of fundamental problems exist: 1) the changes in VMT and tripmaking are difficult to predict accurately, 2) the effects that pricing will have upon vehicle fleet composition and the vehicle operating environment are unclear, 3) the primary operating environment characteristic of concern in the existing modeling regime, average vehicle speed, is difficult to estimate reliably, and finally 4) the cause-effect relationships at work between the vehicle operating environment and emission rates are poorly modeled and highly uncertain anyway, making emission impact assessments using average speed changes very unreliable.

The goal of this paper is to examine the potential air quality impacts likely to result from congestion pricing. A number of key questions must be answered: what effect will congestion pricing have on tripmaking and vehicle miles of travel; how will traffic volumes change on priced and unpriced routes; how will the change in traffic volume affect the operating environment of vehicles (examined as a change in average vehicle speed under the current modeling regime) and the resulting emission rates per unit of vehicle activity; and what are the projected changes in vehicle emissions expected to result from overall changes in vehicle activity and emission rates? In this paper, we focus on the effects of postulated changes in

average vehicle operating speeds on emission rates. An accompanying paper by Harvey (1993a) on changes in travel behavior is used as input to our analysis.

Reductions in vehicle activity and tripmaking and VMT, assuming no changes in vehicle operating conditions, can be readily translated into percentage emission reductions ... although many would argue that even these estimates could be questioned (Guensler 1993a). We do not focus our efforts in this area. Instead, we examine the existing emission modeling regime for average speed changes and provide a range of emission rate changes based upon the projected changes in average vehicle operating speeds. Employing projected changes in average vehicle speeds provided by Harvey (1993a), percent changes in emission rates associated with the implementation of four congestion pricing scenarios are examined.

The large ranges surrounding the projected percent change in emission rates are based upon the confidence intervals associated with the use of speed correction factors as presented in a previous work (Guensler et al. 1993). The actual range in emission rate impact is even greater than presented here, because there are additional sources of uncertainty for which statistical inferences of confidence have yet to be developed, such as the relationship between operating environment and changes in cold and hot start emission rates (Guensler 1993a).

SOURCES OF EMISSION MODELING UNCERTAINTY

Modeling results are highly uncertain because the models were only designed to roughly estimate a "bulk" emission inventory, and were never designed to evaluate policy issues in the manner that they are often employed. Discussions of specific emission modeling problems, including such aspects as off-cycle and modal emissions, characterization of the vehicle fleet, cold- and hot-start emissions, evaporative emissions, potential interaction between emission model correction factors, and specific quantification and spatial allocation of vehicle activity,

can be found in many sources (Guensler 1993a; Harvey 1993b; Bruckman and Dickson 1993; Pollack et al. 1992; Austin et al. 1992; Ashbaugh et al. 1992; TRB 1992; Bruckman and Dickson 1992; Purvis 1992; Benson 1992; Guensler and Geraghty 1991; Gertler and Pierson 1991; SAI 1991; Guensler et al. 1991; Ismart 1991; Lawson et al. 1990; FHWA 1990). The bottom line is that the current modeling methodologies, both for vehicle activity and emission rate estimates, are fraught with uncertainty.

Uncertainty is pervasive in all three emission modeling components: vehicle activity, activity-specific emission rates, and emission rate correction factors. Uncertainty is compounded in the methodologies used to develop the emission inventory. That is, vehicle activity uncertainty is combined with emission rate uncertainty that has already been combined with correction factor uncertainty. However, simple statistical formulae representing suspected ranges of uncertainty cannot be applied to the estimates to determine what the net uncertainty is. There are simply too many unanswered questions regarding the fundamental emission relationships and the basic applicability and usefulness of much of the data collected.

Without detailed re-analysis of the data used to develop the algorithms in existing emission rate models, practitioners cannot accurately identify the individual model components that yield the greatest uncertainty in emission estimates. Confidence interval analysis (based upon re-analysis of the original data) can reveal how representative each of the model algorithms really are. We have undertaken confidence interval analysis using the data originally used to develop the speed correction factors in existing emission rate models (Guensler et al. 1993) and we will employ these confidence intervals in the examination of how congestion pricing is likely to impact average vehicle operating speeds and the resulting gram/mile vehicle emission rates.

CONGESTION PRICING AND EMISSION-PRODUCING VEHICLE ACTIVITIES

The potential impacts of congestion pricing will be revealed through changes in vehicle activity, modeled as resulting from changes in: land use configuration, trip generation, mode choice, trip distribution, and route selection, ideally in an iterative process (Harvey 1993b).

The implementation of congestion pricing may have the following effects on VMT, tripmaking, and trip characteristics, most of which are not accurately (or at all) addressed by travel demand models:

- Generate fewer trips due to increased costs
- Eliminate some non-essential trips and shift others to off-peak periods
- Generate shorter trips due to increased costs
- Partially increase VMT if diversion to unpriced routes occurs
- Generate longer trips if diversions around paid routes exist
- Encourage peak spreading (shift trips to unpriced shoulders of the peak)
- Increase trip chaining activity
- Shift trips to carpools due to increased travel costs
- Shift trips to transit and paratransit due to increased costs
- Change transit access mode
- Change spatial resolution of vehicle route
- Increase average vehicle operating speeds on priced routes
- Reduce modal (acceleration/deceleration) activity and smooth traffic flow

The number of trips undertaken is important from an emission modeling standpoint because the emission levels of all pollutants are elevated during the first few minutes of operation (Jacobs et al. 1990; Heywood 1988; Joy 1992; Stone et al. 1990; Pozniak 1980) and hot and cold start emissions become important contributors to the on-road emissions inventory. In

1987, cold and hot start operations were estimated to contribute about 27 percent of hydrocarbon emissions, 35 percent of CO emissions, and 19 percent of NOx emissions from the automobile fleet in the Los Angeles basin (CARB 1990). Because congestion pricing may change the number of vehicle trips made, emission reductions may result from reduced cold and hot engine starts. Plus, if congestion pricing results in an increase in trip chaining, some cold start trips may be changed to hot start trips, reducing emissions.

Figure 1 illustrates the cumulative hydrocarbon emissions for a typical modern catalyst-equipped vehicle making a ten mile trip at an average speed of 26 mph after a cold start. Note that approximately 55 percent of the hydrocarbon emissions are associated with the cold start, another 10 percent of the emissions with the engine hot soak (evaporation after shutting the engine off), and only 35 percent associated with the hot stabilized combustion on a per mile basis. Although the overall emission rates are much lower, modern, fuel-injected, catalyst-controlled vehicles emit a larger percentage of their emissions during cold start and hot soak than does the average in-use fleet. This indicates that trip-end emissions will become increasingly important as vehicle fleet turnover continues (but may be partially mitigated by new vehicle certification requirements, as manufacturers are expected to achieve much of their reduction in California through the control of cold start emissions).

Harvey's study in the South Coast Air Basin indicates that congestion pricing will have only a modest effect on VMT and tripmaking. Regionwide congestion pricing of \$0.15 per mile (a market clearing price designed to yield a level of service D/E) may yield a VMT reduction of about 5.0 percent and trip reduction of 3.8 percent (Cameron 1991). In reality, this implies roughly a 4 percent decrease in engine start and hot soak emissions and a 5 percent decrease in VMT related emissions. Roughly a 4 percent decrease in automobile emissions overall, provided that vehicle operating conditions remain unchanged.

Yet, it is not likely that emission rates will remain stable as congestion pricing strategies are implemented. Changes in the composition of the vehicle fleet are likely to occur, and congestion reduction yields changes in the vehicle operating environment that in turn affects the magnitude of the emission rates. It is the expected change in vehicle operating conditions and subsequent emission rates that many analysts believe will yield the greatest emission benefit. But how sure are we?

POTENTIAL CONGESTION PRICING IMPACTS ON EMISSION RATES

The magnitude of motor vehicle emission rates are functions of vehicle parameters, fuel parameters, vehicle operating conditions, and the vehicle operating environment. Table 1 illustrates some of the important variables that can be taken into consideration in developing emission rate estimates (Guensler 1993b). Congestion pricing has the capacity to impact vehicle parameters (such as model year, emission control technology, etc.), fuel parameters (i.e. if modes that employ clean fuels are encouraged), and vehicle operating conditions (such as average speed and acceleration).

Vehicle and fuel parameters that affect emission rates are a function of the composition of the vehicle fleet. If the composition of the vehicle fleet changes, fleet average emission rates also change. Recent studies appear to indicate that older vehicles tend to fall into socio-spatial patterns of ownership (Rajan 1993). The vehicle activities undertaken by various socio-economic groups also appear to differ (Micozzi et al. 1993). Because a small fraction of the vehicle fleet is believed to be responsible for a large percentage of fleet emissions (Lawson et al. 1990; Pollack et al. 1992), further studies into the spatial and socioeconomic allocation of super-emitting and malmaintained vehicle activity seems warranted. If VMT and tripmaking reductions are significant in the lower income quintiles and insignificant in the upper income quintiles, and if the ownership and operation of higher-emitting vehicles is higher in either

quintile, the composition of the vehicle fleet will change. This issue is inexorably tied to the equity impacts that also must be addressed prior to the implementation of congestion pricing strategies.

Harvey's work (1993a) indicates that pricing will have a varied impact upon different income groups, noting that congestion pricing of \$0.15 per mile is likely to produce significant reduction in tripmaking and VMT within the first two income quintiles compared to the last two income quintiles. Thus, fleet composition appears likely to change along the affected routes. The composition of the vehicle fleet is also important in terms of estimating emission changes due to changes in operating conditions, because these factors are not independent. Emission behavior with respect to average vehicle speed differs between older and newer vehicle technology groups, complicating the emission impact analyses.

THE SPEED-RELATED MODELING REGIME

The existing baseline exhaust emission rates used in emission models were derived through the testing of thousands of new and in-use motor vehicles upon the federal test procedure (FTP), a certification testing cycle for new vehicles. The FTP consists of a defined set of modal patterns (start, stop, acceleration, deceleration, idling, and constant-speed cruise operations), and is composed of three sub-cycles, known as the Bag 1, Bag 2, and Bag 3 cycles (emissions are collected in separate sample bags for each sub-cycle). Bag 1 contains emissions from a cold engine start and running exhaust, Bag 2 contains only running exhaust emissions and is collected after the engine is hot and combustion is stabilized, and Bag 3 contains emissions from a hot engine start and running exhaust. The bag samples are analyzed to determine the average emission rates for the vehicles operating under the test parameters. In California, the baseline exhaust emission rate for each vehicle class is the average emission result under Bag 2 of the FTP (the hot-stabilized sub-cycle with an average operating speed of 16 mph).

Because the certification cycle is used to test new vehicles, for compliance with federal emissions requirements, as well as in-use vehicles, for evaluation of inspection and maintenance program effectiveness, numerous data are available for vehicles operating under the FTP Bag 2 cycle. However, emission rates noted under the Bag 2 testing conditions can differ significantly from the emission rates for the same vehicle when tested under other hot-stabilized testing cycles. Because thousands of vehicles have been tested under the FTP to develop the baseline exhaust emission rates, the desire on the part of regulatory agencies to define a relationship between baseline emission rates and emission rates at other average speeds seems logical. In this way, ongoing testing of vehicles can be conducted on the single certification cycle, rather than upon numerous cycles (saving substantial agency resources).

To model emission rates at speeds other than 16 mph, the USEPA and CARB developed speed correction factors, or statistically-derived emission ratios (Guensler et al. 1993; USEPA 1992b; CARB 1992a; CARB 1992b; EEA 1991; USEPA 1988). This emission ratio can be thought of as the average emission rate at the speed in question divided by the average emission rate for the same vehicle group under Bag 2 of the FTP. To approximate vehicle emissions at speeds other than 16 mph, the baseline exhaust emission rate is multiplied by the statistically-derived emission ratio. The SCFs were developed through the testing of more than 500 light-duty vehicles on laboratory dynamometers under a variety of chassis dynamometer cycles, including the certification cycle (Guensler et al. 1993).

The current emission inventory methodologies model SCFs and gram/mile vehicle emission rates as non-linear functions of average operating speed. Figures 2 to 4 present the relationships between speed and emissions for modern (1986 and later model year) fuel-injected automobiles. These figures present the multiplier that determines the emission rate for any operating speed, compared to the average emissions for the vehicle class at 16 mph (Bag 2

of the FTP). Thus, in Figure 2, the carbon monoxide emission rate (grams/mile) at 5 mph is modeled to be roughly double that of the baseline exhaust emission rate for an average speed of 16 mph.

Research at the University of California at Davis indicates that speed-related emission factors currently used in emission modeling techniques are highly uncertain (Guensler et al. 1993). These emission correction factors, by the nature of their statistical derivation, yield uncertain results with high standard errors. The dashed lines on Figures 2 to 4 illustrate the 95 percent confidence intervals that surround the speed correction factor curves, based upon statistical analysis of the original data used to develop the speed curves. That is, we are 95 percent confident that the mean response SCF curve for a random sample of vehicles will lie within the confidence interval bounds (Guensler et al. 1993). Thus, in Figure 2, we are 95 percent confident that the carbon monoxide emission rate (grams/mile) at 5 mph is between 1.3 and 2.7 times that of the baseline exhaust emission rate for an average speed of 16 mph. This is a huge range of uncertainty. Yet, there are still additional sources of uncertainty unaccounted for in this analysis (e.g. intercorrelation of variables, representativeness of the test fleet, etc.) that make even these recently-published uncertainty estimates conservative (Guensler et al. 1993).

AVERAGE SPEED ANALYSIS OF CONGESTION PRICING SCENARIOS

The four congestion pricing scenarios examined by Harvey (1993a) include: pricing on some freeways where no alternative routes are available (i.e. bridges), pricing on some freeways where alternative unpriced freeways are available for diversion, pricing on all freeways where alternative unpriced arterials are available for diversion, and pricing on all roads.

Table 2 summarizes the potential changes in average vehicle operating speed on the various affected facilities that are expected to result from the four congestion pricing scenarios

postulated (Harvey 1993a). For example, Harvey's (1993a) analyses indicate that targeted freeway pricing with no alternative unpriced routes (scenario 1) may increase average freeway speeds from 30 mph to 50 mph during the peak periods, and reduce average speeds on the priced freeways during the shoulder of the peak from 55 to 50 mph (due to peak spreading, caused by a price-induced delay in trip start times).

If we were to increase the average speed of travel on a freeway from 30 mph to 50 mph, emission models would predict a decrease in gram/mile emission rates for carbon monoxide and hydrocarbons, and an increase in the emission rates for oxides of nitrogen along these routes. The estimated percent change in emission rates resulting from increased average operating speed were calculated for 1986 and later model year fuel-injected vehicles.

Emissions models would predict that increasing average vehicle operating speeds from 30 mph to 50 mph would decrease carbon monoxide emission rates by 24 percent, decrease hydrocarbon emission rates by 8 percent, and increase oxides of nitrogen emissions by 50 percent for 1986 and later model year fuel injected vehicles

Given the predicted changes in emission rates, one could easily surmise that the increases in average vehicle operating speeds are likely to yield significant reductions in CO and HC emission rates, while concurrently increasing the emission rates of NO_x. However, the point estimates don't tell the whole story. When the calculated emission rate changes include estimates of uncertainty, it becomes clear that the emission change estimates are questionable. For example, we are 95 percent confident that the estimated 24 percent reduction in carbon monoxide emissions associated with increasing average vehicle speeds from 30 mph to 50 mph for 1986 and later model year fuel injected vehicles really lies somewhere between a 72 percent decrease and a 75 percent increase in emission rates. We are dealing with a huge range of uncertainty.

Tables 3 through 5 contain estimates of carbon monoxide, hydrocarbon, and oxides of nitrogen emission rate changes for older-carbureted and modern-fuel-injected vehicles associated with the average vehicle speed changes postulated by Harvey (1993a, see Table 2). A bootstrap approach to estimating combined error (Efron, 1982) was employed to calculate the upper and lower bound estimates in Tables 3 through 5. The predicted error bands around the estimated percent change in emission rate account for the standard deviation of each SCF estimate as well as the covariance between the predicted SCF terms (Guensler, 1993b).

Based upon the analysis of percent emission rate change for combinations of initial and final average speed (in 5 mph increments), the following conclusions can be drawn (Guensler 1993b):

1. Changes in average vehicle speed appear to yield greater percentage changes in carbon monoxide and hydrocarbon emission rates for older carbureted vehicles than for newer fuel injected vehicles (except at speeds exceeding 50 mph where the emission change estimates for older carbureted vehicles are highly uncertain).

2. Changes in average vehicle speed yield appear to provide greater percentage changes in oxides of nitrogen emission rates for newer fuel injected vehicles than for older carbureted vehicles.

3. Percentage changes in emission rates appear more stable (i.e. the confidence band is narrower) for older carbureted vehicles than for newer fuel injected vehicles, making the percentage change estimates more certain for older carbureted vehicles than for newer fuel injected vehicles (except at speeds exceeding 50 mph where the emission change estimates for older carbureted vehicles are highly uncertain).

4. Predicted increases in emission rates are fairly certain for all pollutants when moving toward extremely low speeds (i.e. 5 mph) and predicted decreases are fairly certain for all pollutants when moving from extremely low speeds.

5. Increasing average vehicle speeds from low speeds (0 to 30 mph) to moderate speeds (between 30 and 45 mph) should provide carbon monoxide benefits for older vehicles, and

hydrocarbon emission benefits for all vehicles. However, the carbon monoxide benefits for modern fuel injected vehicles associated with these speed changes are highly uncertain.

6. Increasing average vehicle speeds from very low speeds (below 15 mph) to low to moderate speeds (perhaps between 15 and 40 mph) should provide an emission benefit for oxides of nitrogen.

7. Model-predicted emission changes for carbon monoxide and hydrocarbons are extremely variable for increases from moderate to very high average travel speeds. However, based upon the presumed cause-effect relationship between engine load and vehicle enrichment, moving toward very high free flow travel speeds from moderate travel speeds is likely to significantly increase emission rates and prove detrimental to air quality. It is probably reasonable to expect increases in both hydrocarbon and carbon monoxide emission rates at high speeds even though the confidence bands are wide.

8. Changes in carbon monoxide and hydrocarbon emission rates associated with small relative average speed changes at high speeds (e.g. increasing average speed from 50 mph to 55 mph) are too uncertain to accurately assess. Given the highly variable response of vehicles to the changes in average test cycle speed, the limited number of vehicles tested, and the nature of the high speed cycles themselves (high initial acceleration rates), the high degree of uncertainty is to be expected for carbon monoxide and hydrocarbon emissions.

9. Decreasing average vehicle speeds from above 60 mph to below 55 mph (but remaining above 35 mph) is likely to provide large emission benefits for oxides of nitrogen, moderate emission benefits for hydrocarbons, and may also provide carbon monoxide benefits (as indicated by bootstrap analysis).

10. The average speed modeling regime for oxides of nitrogen is probably not unreasonable. The range of confidence for changes in oxides of nitrogen emissions is narrow even for high speed operations, indicating that the oxides of nitrogen increases are likely to be significant and fairly certain at high speeds. Because emissions of oxides of nitrogen are important in terms of ozone formation than was previously realized by air quality management planning agencies (NRC 1991), evaluation of oxides of nitrogen emissions changes is paramount in congestion pricing impact assessments for many areas.

11. The application of speed correction factors and the average speed modeling regime to analysis of emissions along corridors will yield highly uncertain results.

EFFECTS OF MODAL ACTIVITY

Average speed does not cause emissions. Two trips with the same average speed can be made by a vehicle, but the emissions from each trip may differ significantly because emissions are a function of combustion parameters and emission control systems. The modal characteristics of the trip (acceleration, deceleration, cruise and idle patterns) appear to be much more likely to cause changes in the combustion parameters and control system efficiency than the average speed.

Second-by-second laboratory tests indicate that changes in operating mode (acceleration and deceleration) are capable of producing significant emissions, but are not currently modeled (Darlington et al. 1992; CARB 1991; Benson 1989; Groblicki 1990; Calspan 1973; Kunselman et al. 1974). Recent laboratory testing indicates that high acceleration rates are significant contributors to instantaneous emission rates, and that one sharp acceleration may cause as much carbon monoxide pollution as does the entire remaining trip (CARB 1991; Carlock 1992). Pollutant "emission puffs" do occur, typically when the vehicle goes into enrichment and not enough air is available to facilitate complete combustion, and these events may be associated with high rates of acceleration or deceleration. Surprisingly, even vehicle operations at a relatively stable high speed flow appear to show some variability in emission rates that may be associated with accelerations and decelerations, even though the rates of acceleration and deceleration at these speeds are low (Guensler 1993a). Modal effects are not directly addressed in 'average speed' emissions analysis.

Congestion pricing is likely to smooth vehicle flows and reduce the number of significant acceleration and deceleration events that cause elevated emission rates. But the impact of flow smoothing is not well represented in the average speed modeling regime based upon the limited number and variety of test cycles employed in developing the relationships (Guensler et al. 1993). Better tools are needed to assess both the actual changes in modal operations as well as the changes in emission rates associated with these changes in modal operations.

We can postulate, however, that when congestion pricing smoothes vehicle flows on freeways, emission reductions will result. Similarly, if congestion pricing causes increased congestion on arterials, emission increases will result. When examining the changes postulated for average vehicle operating speed, we can assert that when average speed increases and flows are smoothed, the change in emission rate should be toward the optimistic end of the confidence interval. Concurrently, we can assert that when average speeds decrease and flows become less smooth, the change in emission rate should be toward the pessimistic end of the confidence interval.

CONCLUSIONS

The emissions impacts of congestion pricing on tripmaking and VMT are relatively straightforward if the operating environment of the vehicle remains unchanged. A percentage reduction in trip ends (starts and engine shutdowns) can be translated into percentage changes in trip-end emissions. Similarly, reductions in VMT can be translated into reductions in running emissions. However, recent research (Cameron 1991; Harvey 1993a) indicates that pricing-induced changes in tripmaking and VMT are expected to be small (less than 5 percent). Rather, analysts have been advocating congestion pricing primarily for the benefits in reducing traffic congestion, expecting that the changes in the vehicle operating environment (i.e. average speed) will produce significant emission reductions.

Our analyses indicate, however, that changes in average vehicle operating speed yield highly uncertain emission impact estimates. Even so, a number of conclusions can be drawn from the analyses. If congestion pricing policies are implemented, we can be fairly certain that they should be designed to : 1) increase average vehicle speeds from below 15 mph to above 15 mph (but to remain below 40 mph) for emission benefits in all pollutants, 2) increase average

vehicle speeds from below 30 mph to above 30 mph (but to remain below 40 mph) in areas where reductions in carbon monoxide and hydrocarbon emissions are desired, 3) avoid allowing previously congested routes to exceed 40 mph average speed as a result of the pricing policy, and 4) avoid creating congestion on arterial unpriced routes. Thus, from an air quality perspective, congestion pricing is recommended only in areas where average speeds are currently below 35 mph (demand exceeds capacity). Market clearing prices should be set so that average speeds do not increase beyond 40 mph. Pricing strategies should also ensure that significant reductions in average vehicle speeds do not result on arterials.

Because the travel demand and emission rate models do not well represent the actual cause-effect relationships at work (especially for modal activities), it is impossible to determine in a definitive manner the overall emission impacts of congestion pricing policies. However, many of the changes noted in vehicle activity and the factors that affect emission rates are positive from the perspective of cleaning the air. The likely impacts of congestion pricing on vehicle activity and the variables that affect vehicle emission rates are summarized in Table 6.

Because changes in average vehicle speed yield significantly different percent changes in emission rates for older carbureted vehicles and newer fuel injected vehicles (as well as relative certainty associated with these percentage changes), the fleet composition under congestion pricing scenarios is important. If the bottom two income quintiles own a greater percentage of carbureted vehicles and are also impacted more by congestion pricing (i.e. trips and VMT are reduced to a greater extent) than those in the upper income quintiles, fewer of the older vehicles will be present in the post-pricing fleet. Thus, the composition of the vehicle fleet resulting from congestion pricing (i.e. the vehicle and fuel parameters affecting fleet emission rates) may play a significant role in net emissions estimates and should be examined in detail. This factor will probably create equity considerations that will need to be addressed.

Because congestion reductions (or increases on arterials) that arise from congestion pricing will yield changes in vehicles' modal operating environment. When average speed increases and flows are smoothed, the change in emission rate should be toward the optimistic end of confidence intervals. When average speeds decrease and flows become less smooth, projected emission rate changes should be toward the pessimistic end of the confidence intervals.

FURTHER STUDIES

Over the short term, the USEPA is evaluating the FTP and will likely make changes to the test method (Guensler 1993a). However, because the FTP improvement effort only directly addresses adequacy of baseline exhaust emission rate estimates, it is unlikely that estimation of the emission inventory and analysis of scenarios such as congestion pricing will be significantly improved. Further research into modal modeling, being undertaken by Georgia Tech., the University of California at Los Angeles, and the University of California at Davis, should help shed some light on the significance of the modal emissions component in the evaluation of congestion pricing scenarios. Disaggregate data are now becoming available for instrumented vehicles and modeling work in this area is ongoing. But, the development of significantly improved emission inventory modeling methodologies will require the collection and analysis of huge amounts of new data, on new testing cycles and new testing equipment, probably with second-by-second emission resolution (Guensler 1993a).

It took us more than one year to assess the uncertainty associated with the use of speed correction algorithms in the models, so modelers are a long way off from deriving uncertainty estimates around other modeling components. Nevertheless, the re-analysis of speed correction factors demonstrates how other modeling components could be examined, if sufficient resources were allocated and how uncertainty analysis for each modeling component could be incorporated into the analytical framework. Note also that this paper did not examine

sensitivity analysis of the models. That is, we did not address how sensitive the models are to errors in estimation of the independent variable, average speed (see Bruckman and Dickson 1992).

Keeping in mind that this paper only examined estimates of uncertainty in percentage change in emission rates, a detailed empirical study of net emissions change should follow. The new analysis would employ predicted changes in number of trips, predicted changes in VMT along each route, predicted changes in average speeds along each route, and speed correction factor uncertainty estimates from Guensler, et al. (1993) to predict the total emission impacts of the proposed congestion pricing policies as well as the confidence intervals around the predictions.

Decisions being made in the air quality and transportation arena are made in the face of tremendous uncertainty. Most decisions, unfortunately, are made by policy-makers without the benefit of knowing the magnitude of uncertainties involved. This problem arises partly from the fact that not enough research on emission rate and activity uncertainty has been conducted, and in part from the fact that institutional policy-oriented learning is a slow process hindered by the structure and nature of the policy arena. Hopefully this paper will help apprise policy makers of the tremendous uncertainty involved in trying to assess the emissions impacts of policies designed to change average vehicle speeds, and will communicate the need to gather, disseminate, and analyze new and better emissions data.

REFERENCES

- Ashbaugh, L., D.R. Lawson, G.A. Bishop, P.L. Guenther, D.H. Stedman, D.R. Stephenson, P.J. Groblicki, Jayendra S. Parikh, Brian R. Johnson, and Steve C. Huang. 1992. On-Road Remote Sensing of Carbon Monoxide and Hydrocarbon Emissions During Several Vehicle Operating Conditions. Manuscript, Submitted to Journal of the Air and Waste Management Association. Pittsburgh, PA. 1992.
- Austin, Thomas C., Thomas R. Carlson, Francis J. DiGenova, John M. Lee, and Mark Carlock. 1992. An Analysis of Driving Patterns in Los Angeles During 1992. A Paper Presented at the Third Annual CRC-APRAC On Road Vehicle Emissions Workshop. Coordinating Research Council. Atlanta, GA. September 1992.
- Benson, Paul. 1989. CALINE4 - A Dispersion Model for Predicting Pollutant Concentrations Near Roadways Report FHWA/CA/TL-84/15. State of California Department of Transportation, Division of New Technology and Research. Sacramento, CA. November 1984, Revised June 1989.
- Benson, Paul. 1992. Data Requirements for Micro-Scale Modeling of Mobile Sources. Transportation Modeling Tips and Trip-Ups Proceedings, an Air and Waste Management Association Specialty Conference. Pittsburgh, PA. March 1992.
- Bevington, Philip R, and D. Keith Robinson. 1992. Data Reduction and Error Analysis for the Physical Sciences. McGraw Hill, Inc. New York, NY. 1992, 1969.
- Bruckman, Leonard and Edmund L. Dickson. 1992. Case Study - South Coast On-Road Motor Vehicle Emission Inventory Process. Transportation Modeling Tips and Trip-Ups Proceedings, an Air and Waste Management Association Specialty Conference. Pittsburgh, PA. March 1992.
- Bruckman, Leonard and Edmund L. Dickson. 1993. Preparation of Transportation Data for Use in Emissions Models (930333). A Paper Presented at the 72nd Annual Meeting of the Transportation Research Board. Washington, DC. January 1993.
- CARB, California Air Resources Board. 1989. California Air Resources Board. The Transportation and Air Quality Linkage. Office of Strategic Planning. Sacramento, CA. 1989.
- CARB, California Air Resources Board. 1990. California Air Resources Board. Emission Inventory 1987. Technical Support Division. Sacramento, CA. March 1990.
- CARB, California Air Resources Board. 1991. California Air Resources Board. Modal Acceleration Testing. Mailout No. 91-12. Mobile Source Division. El Monte, CA. March 20, 1991.
- CARB, California Air Resources Board. 1992a. Methodology to Calculate Emission Factors for On-Road Motor Vehicles. Technical Support Division. Sacramento, CA. 1992.
- CARB, California Air Resources Board. 1992b. California Air Resources Board. Derivation of the EMFAC7F Speed Correction Factors. Mobile Source Division, Inventory Analysis Branch, Analysis Section. El Monte, CA. July 1992.
- Caltrans, California Department of Transportation. 1992. Background Paper Regarding EMFAC7EPSCF Speed Correction Factors Re-Released by the ARB on November 25, 1992. Available through Steve Borroum, Caltrans - OPPD. Sacramento, CA. December 2, 1992.
- Calspan Corporation. 1973a. A Study of Emissions from Light-Duty Vehicles in Six Cities. Buffalo, NY. Prepared for the Environmental Protection Agency (Document #APTD-1497), Office of Mobile Source Air Pollution Control. Ann Arbor, MI. March 1973.

Calspan Corporation. 1973b. Automobile Exhaust Emission Surveillance (PB-220 775). Buffalo, NY. Prepared for the Environmental Protection Agency (Document #APTD-1544), Office of Mobile Source Air Pollution Control. Ann Arbor, MI. May 1973.

Cameron, Michael. 1991. Transportation Efficiency: Tackling Southern California's Air Pollution and Congestion. Environmental Defense Fund. Washington, DC. March 1991.

Carlock, Mark. 1992. Overview of Exhaust Emission Factor Models. In: Proceedings, Transportation Modeling: Tips and Trip Ups. Air and Waste Management Association. Pittsburgh, PA. March 1992.

Darlington, Thomas L., Patricia E Korsog, and Robert Strassburger. 1992. Real World and Engine Operation: Results of the MVMA/AIAM Instrumented Vehicle Pilot Study. Proceedings of the 85th Annual Meeting of the Air and Waste Management Association. Pittsburgh, PA. June 1992.

DeLuchi, Mark, Quanlu Wang, and David L. Greene. 1992. Motor Vehicle Fuel Economy, the Forgotten HC Control Strategy? Report ORNL-6715. Oak Ridge National Laboratory. Oak Ridge, TN. June 1992.

EEA, Energy and Environmental Analysis. 1991. Speed Correction Factors for the Updated Version of MOBILE4. Arlington, VA. Prepared for the U.S. Environmental Protection Agency. Ann Arbor, MI. Contract No. 68-CO-0065, Work Assignment #3. August 1991.

FHWA, Federal Highway Administration. 1992a. A Summary: Air Quality Provisions of the Intermodal Surface Transportation Efficiency Act of 1991. Publication No. FHWA-PD-92-022. US Department of Transportation, Federal Highway Administration. Washington, DC. 1992.

FHWA, Federal Highway Administration. 1992b. A Summary: Transportation Provisions of the Clean Air Act Amendments of 1990. Publication No. FHWA-PD-92-023. US Department of Transportation, Federal Highway Administration. Washington, DC. 1992.

FHWA, Federal Highway Administration. 1990. Federal Highway Administration. Calibration and Adjustment of System Planning Models (FHWA-ED-90-015). US Department of Transportation, Federal Highway Administration. Washington, DC. December 1990

GAO, General Accounting Office. 1991. Traffic Congestion: The Need and Opportunity for Federal Involvement (GAO/T-PEMD-91-10). Testimony of Eleanor Chelimsky, Assistant Comptroller General, Before the Committee on the Budget, US House of Representatives. May 29, 1991.

Gertler, Alan W. and William R. Pierson. 1991. Motor Vehicle Emissions Modeling Issues (91-88.8). Air and Waste Management Association, 84th Annual Meeting Proceedings. Pittsburgh, PA. June 1991.

Groblicki, Peter J. 1990. Presentation at the California Air Resources Board Public Meeting on the Emission Inventory Process. General Motors Research Laboratories. Warren, MI. November 5, 1990.

Guensler, Randall. 1993a. Transportation Data Needs for Evolving Emission Inventory Models. Proceedings: Transportation Planning and Air Quality II. American Society of Civil Engineers. New York, NY. May 1993.

Guensler, Randall. 1993b. Vehicle Emission Rates and Average Vehicle Operating Speeds. Dissertation. submitted in partial satisfaction of the requirements for the degree of Doctor of Philosophy in Civil/Transportation Engineering. Department of Civil Engineering, University of California, Davis. Davis, CA. Forthcoming in September 1993.

Guensler, Randall. 1992. Equity Dilemmas Associated with Command and Control and Market-Based Approaches to Air Pollution Control (92-176.01). Air and Waste Management Association, 85th Annual Meeting Proceedings. Pittsburgh, PA. June 1992.

Guensler, Randall, Simon Washington and Daniel Sperling. 1993. A Weighted Disaggregate Approach to Modeling Speed Correction Factors (UCD-ITS-RR-93-6). Institute of Transportation Studies. University of California, Davis. Davis, CA. April 1993.

Guensler, Randall, Anne B. Geraghty, and Pam Burmich. 1992. The Role of Transportation Control Measures in California's Air Pollution Control Strategy. In: Transactions, PM₁₀ Standards and Nontraditional Particulate Source Controls. Air and Waste Management Association. Pittsburgh, PA. January 1992.

Guensler, Randall, Daniel Sperling, and Paul P. Jovanis. 1991. Uncertainty in the Emission Inventory for Heavy-Duty Diesel-Powered Trucks (UCD-ITS-RR-91-02). Institute of Transportation Studies. University of California, Davis. Davis, CA. May 24, 1991.

Guensler, Randall, and Anne B. Geraghty. 1991. A Transportation/Air Quality Research Agenda for the 1990's (91-87.2). Air and Waste Management Association, 84th Annual Meeting Proceedings. Pittsburgh, PA. June 1991.

Hahn, Robert W., and R.N. Stavins. 1990. Market-Based Environmental Regulation: A New Era from an Old Idea? (90-155.7). Proceedings of the 83rd Annual Meeting of the Air and Waste Management Association. Pittsburgh, PA. June 1990.

Harvey, Greig. 1993a. Transportation Pricing and Travel Behavior. Proceedings of the TRB/CBASSE Congestion Pricing Symposium. Washington, DC. June 1993.

Harvey, Greig. 1993b. Manual of MPO Modeling Practice. National Association of Regional Councils. Washington, DC. 1993.

Heywood, John B. 1988. Internal Combustion Engine Fundamentals. McGraw-Hill Publishing Company. New York, NY. 1988.

Ismart, Dane. 1991. Travel Demand Forecasting Limitations for Evaluating TCMs. A Paper Presented at the 84th Annual Meeting of the Air and Waste Management Association. Copies available from author at the Federal Highway Administration. Washington, DC. June 1991.

Jacobs, Paul, Donald J. Churnich, and Mark A. Burnitzki. 1990. Motor Vehicle Emissions and their Controls. California Air Resources Board. Sacramento, CA. July, 1990.

Joy, Richard W. 1992. Drive Thru Windows - A Case Study. Proceedings of the Transportation Modeling Tips and Trip-Ups Conference. Air and Waste Management Association. Pittsburgh, PA. March 11-12, 1992.

Ketcham, Brian. 1991. Making Transportation Choices Based on Real Costs. Koinam and Ketcham. Brooklyn, NY. October 1991.

Kunselman, P., H.T. McAdams, C.J. Domke, and M.E. Williams. 1974. Automobile Exhaust Emission Modal Analysis Model. Calspan Corporation. Buffalo, NY. Prepared for the Environmental Protection Agency (Document 460/3-74-005), Office of Mobile Source Air Pollution Control. Ann Arbor, MI. January 1974.

Lawson, Douglas R., Peter J. Groblicki, Donald H. Stedman, Gary A. Bishop, and Paul R. Guenther. 1990. Emissions from In-Use Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program. Journal of the Air and Waste Management Association. Volume 40, Number 8. pp. 1096-1105. Pittsburgh, PA. August 1990.

Micozzi, Martine, and Peter Bowen, Editors. *Running on Empty: The Travel patterns of Extremely Poor People in Los Angeles*. A Paper Presented at the 1993 Annual Meeting of the Transportation Research Board. January 1993.

NRC, National Research Council. 1991. *Rethinking the Ozone Problem in Urban and Regional Air Pollution*. National Academy Press. Washington, DC. 1991.

Pollack, Alison, Jeremy G. Heiken, and Robert A. Gorse. 1992. *Comparison of Remote Sensing Data and Vehicle Emission Models: The High Proportion of Emissions from High Emitting Vehicles*. Proceedings of the 85th Annual Meeting of the Air and Waste Management Association. Pittsburgh, PA. June 1992.

Pozniak, Donald J.. 1980. *The Exhaust Emission and Fuel Characteristics of an Engine During Warmup A Vehicle Study (800396)*. Society of Automotive Engineers. Warrendale, PA. February 1980.

Purvis, Charles. 1992. *Sensitivity of Transportation Model Results to Uncertainty in Input Data*. Transportation Modeling Tips and Trip-Ups Proceedings, an Air and Waste Management Association Specialty Conference. Pittsburgh, PA. March 1992.

Rajan, Sudhir. 1993. *Socio-Spatial Patterns of Vehicle Ownership in Southern California: I Preliminary Study*. Proceedings of the 86th Annual Meeting of the Air and Waste Management Association. Pittsburgh, PA. June 1993.

Regulatory Flexibility Group. 1991. *A Marketable Permits Program for the South Coast: Recommendations of the Regulatory Flexibility Group*. A Coalition of Southern California Businesses and Associations. Latham and Watkins. Los Angeles, CA. December 20, 1991.

SAI, Systems Applications International. 1991. *Assessment of Computer Models for Estimating Vehicle Emission Factors, Volume III: Sensitivity Analyses of the MOBILE4 and EMFAC7E Emission Models (SYSAPP-91/091c)*. San Rafael, CA. July 1991.

South Coast Air Quality Management District. 1991. *Marketable Permits Program*. Working Papers 1-4. El Monte, CA. 1991.

Stone, C.R., A.J. Sorrell, T.W. Biddulph, and R.A. Marshall. 1990. *Analysis of Spark-Ignition Engine Performance after Cold Start, with Thermal and Cyclic Measurements*. Proceedings of the Institution of Mechanical Engineers, International Conference on Automotive Power Systems Environment and Conservation. Mechanical Engineering Publications, Ltd.. Suffolk, England. September 1990.

Taylor, John R. *An Introduction to Error Analysis*. University Science Books. Mill Valley, CA. 1982.

TRB, Transportation Research Board. 1992. *Environmental Research Needs in Transportation*. Transportation Research Circular, Number 389. Washington, DC. March 1992.

USEPA, US Environmental Protection Agency. 1988. *Mobile 4.0 Workshop Materials*. Office of Mobile Sources. Ann Arbor, MI. December 20, 1988.

USEPA, US Environmental Protection Agency. 1992a. *Proceedings of the Innovative Regulatory Strategies Workshop*. Office of Policy, Planning and Research. Washington DC. January 1992.

USEPA, US Environmental Protection Agency. 1992b. *Mobile 5.0 Workshop Materials*. Office of Mobile Sources. Ann Arbor, MI. March 5, 1992.

Table 1
Vehicle Parameters, Fuel Parameters, Vehicle Operating Conditions, and
Environmental Conditions Known to Affect Motor Vehicle Emission Rates (Guensler 1993b)

<p>Vehicle Parameters:</p> <ul style="list-style-type: none"> • Vehicle class [weight, engine size, HP, etc.]* • Model year • Accrued vehicle mileage • Fuel delivery (e.g. carbureted or fuel injected) • Emission control system • Onboard computer control system • Control system tampering • Inspection and maintenance history 	<p>Fuel Parameters:</p> <ul style="list-style-type: none"> • Fuel type • Oxygen content • Fuel volatility • Sulfur content (SO_x precursor) • Benzene content • Olefin and aromatic content • Lead and metals content • Trace sulfur effects on catalyst efficiency*
<p>Vehicle Operating Conditions:</p> <ul style="list-style-type: none"> • Cold or hot start mode (unless treated separately) • Average vehicle speed • Modal activities that cause enrichment* • Load (e.g. A/C, heavy loads, or towing) • Influence of driver behavior* 	<p>Vehicle Operating Environment:</p> <ul style="list-style-type: none"> • Altitude • Humidity • Ambient temperature • Diurnal temperature sweep • Road grade*

* These components are not explicitly included in the USEPA and CARB emission rate models

Table 2
 Changes in Average Vehicle Speed
 Resulting from Four Postulated Pricing Scenarios (Harvey 1993a)

Pricing Scenario	Changes in Average Vehicle Speed by Facility
Targeted Freeway Pricing (no alternative unpriced routes)	Priced Freeways (peak): 30 → 50 mph Priced Freeways (peak shoulder): 55 → 50 mph Other Facilities: No Change
Partial Freeway Pricing (alternative unpriced freeways) (alternative unpriced arterials)	Priced Freeways (peak): 30 → 45 mph Unpriced Freeways (peak): 40 → 35 mph Freeways (peak shoulder): Uncertain Other Facilities: Uncertain
Comprehensive Freeway Pricing (alternative unpriced arterials)	Priced Freeways (peak): 30 → 45 mph Unpriced Arterials (peak): 30 → 20 mph Peak Shoulder: Modest declines
Comprehensive Pricing (no alternative unpriced routes)	Uncertain Changes Higher Speeds Everywhere

Table 3
Predicted Change in Gram/Mile CO Emission Rates
(with 95% upper and lower confidence limits)
Resulting from Postulated Changes in Average Vehicle Operating Speed (mph)
Bootstrap Approach

Change in Average Speed	Percent Change in Gram/Mile Carbon Monoxide Emission Rate for 1986 and Later Model Year Fuel Injected Vehicles		
	High	Pred.	Low
30 → 50	-72	-24	+75
30 → 65	+5	+105	+234
55 → 50	-51	-22	-2
30 → 45	-72	-25	+50
40 → 35	-14	+17	+58
30 → 20	0	+22	+58

Table 4
Predicted Change in Gram/Mile HC Emission Rates
(with 95% upper and lower confidence limits)
Resulting from Postulated Changes in Average Vehicle Operating Speed (mph)
Bootstrap Approach

Change in Average Speed	Percent Change in Gram/Mile Hydrocarbon Emission Rate for 1986 and Later Model Year Fuel Injected Vehicles		
	High	Pred.	Low
30 → 50	-48	-8	+68
30 → 65	-1	+90	+220
55 → 50	-33	-17	-2
30 → 45	-47	-17	41
40 → 35	-13	+9	+26
30 → 20	+11	+30	+76

Table 5
 Predicted Change in Gram/Mile NOx Emission Rates
 (with 95% upper and lower confidence limits)
 Resulting from Postulated Changes in Average Vehicle Operating Speed (mph)
 Bootstrap Approach

Change in Average Speed	Percent Change in Gram/Mile Oxides of Nitrogen Emission Rate for 1986 and Later Model Year Fuel Injected Vehicles		
	High	Pred.	Low
30 → 50	+32	+50	+71
30 → 65	+110	+175	+251
55 → 50	-22	-18	-14
30 → 45	+16	+25	+36
40 → 35	-11	-8	-5
30 → 20	+15	+25	+39

Table 6
Potential Impacts of Congestion Pricing
on Emission-Producing Vehicle Activities,
and on Variables Expected to Affect Vehicle Emission Rates

Emission-Producing Activities	
Vehicle Miles Traveled	↓
Engine Starts and Hot Soaks	↓
Diurnal Evaporation	NC
Vehicle Refueling ^a	↓
Modal Behavior (and Idling) ^b	↓↑
Vehicle and Fuel Parameters	
Vehicle Age ^c	↓
Accrued Vehicle Mileage	↓
Tampering and I&M ^c	↓
Vehicle Operating Conditions	
Average Vehicle Speed ^d	↓↑
Vehicle Load	↓

- a Changes in emissions associated with vehicle refueling will also be a function of changes in tripmaking as well as changes in fuel efficiency associated with retained trips (DeLuchi et al. 1992).
- b Pricing will reduce congestion and pollutant emission rates from modal activities on routes where flows are smoothed. However, reductions cannot be reliably quantified at this time. Note also, emissions may increase along those routes that become more congested as a result of vehicle diversion.
- c Congestion pricing may result in a change in vehicle fleet composition. The demand elasticity for operators of older vehicles will likely yield a smaller percentage of older vehicles in the peak period fleet. In general, older vehicles have higher emission rates and are more likely to be tampered (although this assertion is currently being debated). Because the emissions behavior of older and newer vehicles is significantly different, the potential emissions impact of fleet composition is important. Note: potential impact on fleet composition may also have serious equity implications.
- d The emission rate decreases are for CO and HC, and increases will result for NOx. Note also that emission rates for all pollutants may be substantially increased if high speed operations result.

(NC) = Not Likely to Significantly Change Activity or Emission Rates

(↑) = Likely to Increase Activity or Emission Rates

(↓) = Likely to Decrease Activity or Emission Rates

(↑↓) = Likely to Partially Increase and Partially Decrease Activity or Emission Rates

(U) = Uncertain Impacts

Faint, illegible text, possibly bleed-through from the reverse side of the page. The text is arranged in several paragraphs separated by horizontal lines.

Second section of faint, illegible text, also appearing to be bleed-through from the reverse side. It contains several lines of text with some horizontal line breaks.

Figure 1

Cumulative Emissions vs. Time

VOC Emissions

1987 Average Fleet Vehicle (w/Catalyst)

10 Mile Trip @ 26 mph Average Speed

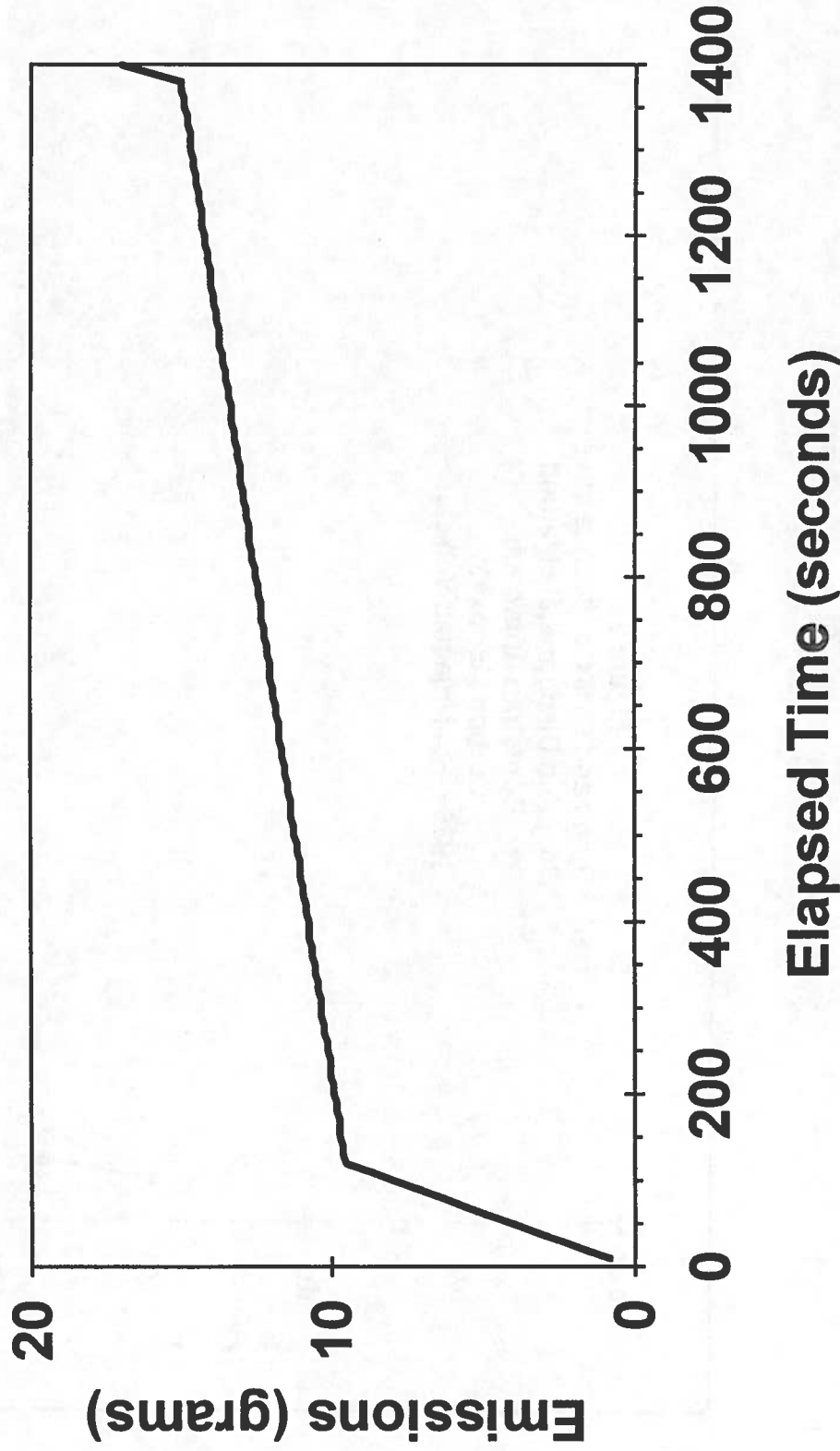


Figure 2
SCF (g/mi) and 95% Confidence Interval
Weighted Disaggregate Method
Bootstrap Approach
Carbon Monoxide
1986+, Fuel Injected Vehicles

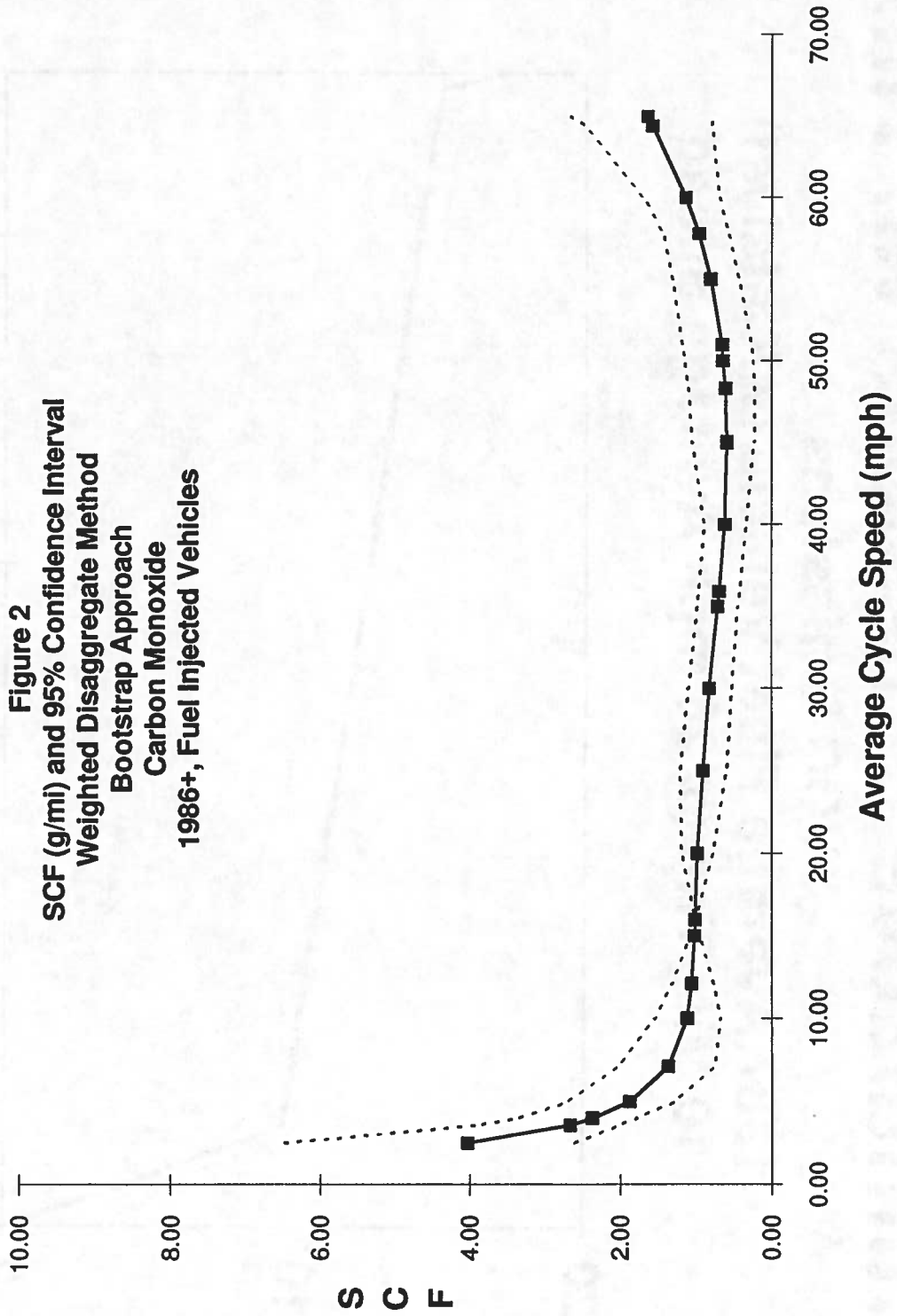


Figure 3
SCF (g/mi) and 95% Confidence Interval
Weighted Disaggregate Method
Bootstrap Approach
Hydrocarbons
1986+, Fuel Injected Vehicles

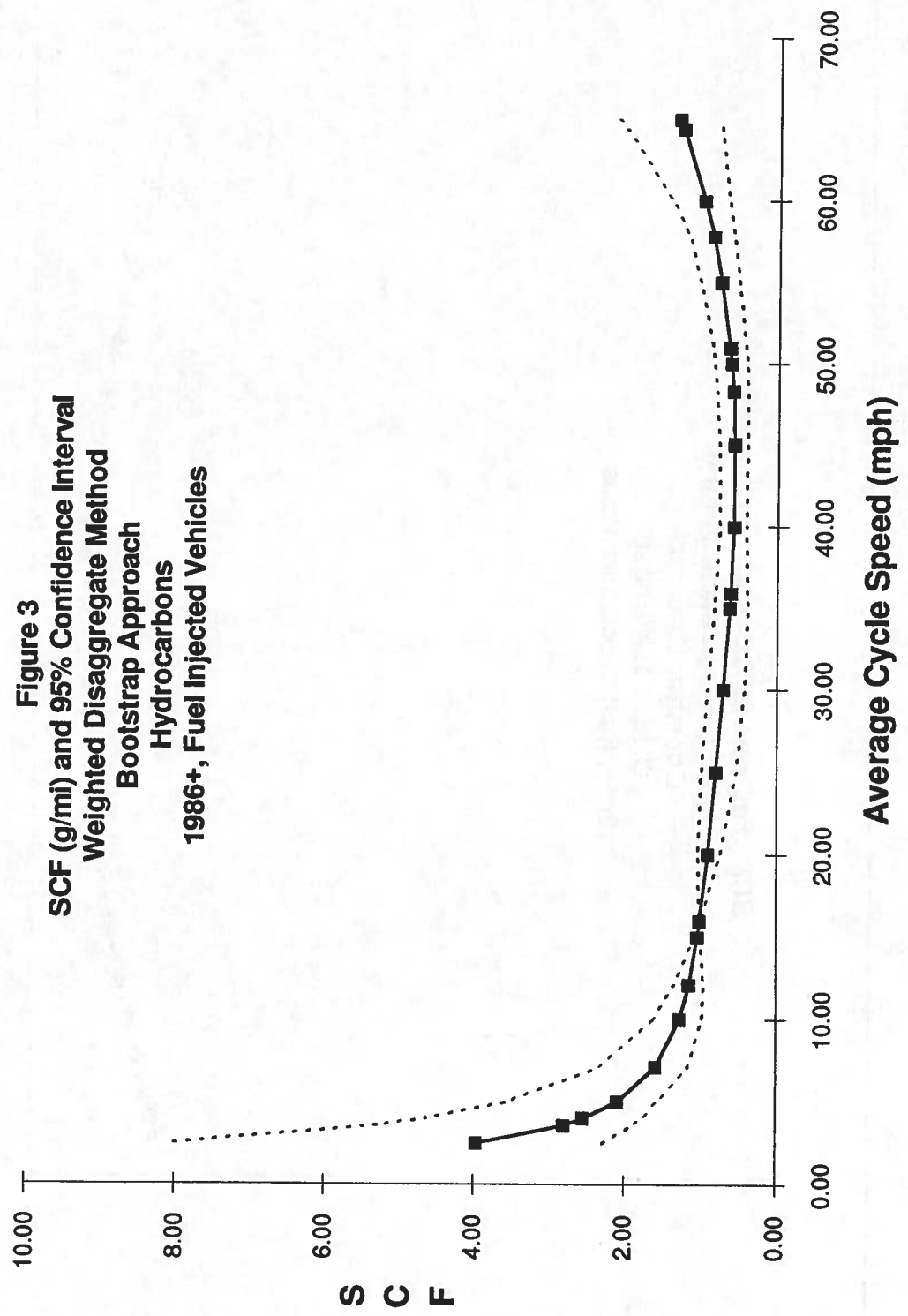


Figure 4
SCF (g/mi) and 95% Confidence Interval
Weighted Disaggregate Method
Bootstrap Approach
Oxides of Nitrogen
1986+, Fuel Injected Vehicles

