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TRAFFIC ACCIDENTS, TIME VALUE AND THE BENEFITS OF IMPROVEMENTS IN ENVIRONMENTAL VISIBILITY

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ABSTRACT

In the 1977 Amendments to the Clean Air Act Congress directed the Environmental Protection Agency to develop regulations aimed at remedying existing visibility impairments caused by man-made pollutants. The benefits of environmental visibility improvement include reductions in visibility-related health problems, increases in recreational activities, property value and rent increases resulting from good view, improvements in transportation and related business activities, increases in traffic safety, value of travel time saved by motorists, etc. This study uses multiple regression and linear probability models to estimate the monetary value of improvements in traffic safety and time saved by motorists in Cook County, Illinois, as visibility improves. Our results show that ten percent improvement in visibility reduces non-fatal accidents by 15.6 units per day, increases the probability of fatalities by 0.023 per day and reduces travel time by 0.34 miles per hour, yielding an aggregate net benefit of 43 million dollars per year in Cook County.

INTRODUCTION

Effective emission control practices lead to improved health, increased recreational activities, reduced damages to vegetation and rivers, and other benefits. Pollution abatement also improves the clarity of the environment, which has immediate aesthetic and psychological benefits. Environmental clarity may also affect aviation and automobile traffic safety. The United States Department of

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Transportation [1] reports that 14 percent of the traffic fatalities which occurred in 1979 were associated with bad weather. Although poor visibility cannot be expected to be a dominant factor in causing traffic casualties, any comprehensive study of the benefits of improving visibility must include the value of accidents avoided, if any, and the value of time saved by motorists as visibility improves.

In this article an attempt is made at estimating and valuing the effect of visibility improvement on fatal and non-fatal accidents and the value of time saved by motorists.

Visibility, or visual range, can be defined as the maximum distance from an observer at which a (large) dark object or a marker disappears against the horizon [2]. It depends on the human perception of distance, clarity, texture, color and contrast change. The visual condition of the observer and the quality of the object to be observed will most likely affect the visibility measures.

Colored clouds, smoke, and man-made haze—visible air pollution—are the products of industries, traffic and other sources of airborne pollutants. Haze-forming particles either absorb or scatter light, creating hazes that limit an observer's view. Fine particles, usually not exceeding 2.5 micrometer in diameter, cause most of the visibility problems [3]. Sulfates, which tend to fall within the particle size range of 0.1 to 1.0 micrometers and are formed from the transformation of gaseous sulfur dioxide emissions from power plants, refineries, oil and gas fields and smelters, are the major contributors to visibility impairment in the United States. It can be expected that pollution abatement regulations will improve visibility.

Trijonis and Yuan estimate that sulfates contribute to approximately 50 percent of visibility impairment in the northeastern United States [4]. In the Colorado Plateau Joseph reports that sulfate particles are responsible for 40-65 percent of the visibility impairment [3]. Nitrates, carbon, ozone and other suspended particulates also contribute to visibility impairment. Generally, visibility is lowest in the northeast, ranging from 8 to 14 miles. It ranges from 30 to 80 miles in the southwest. The lowest visual range in the west is in the coastal areas of California and Washington [3]. In the Chicago area, daily average visibility data collected between January 1978 and June 1980 show an average visibility of 10.3 miles, ranging from 0.31 to 16.7 miles. A visibility level of 0.3 must impose some costs on people whose businesses depend significantly on good visibility.

The 1977 amendments to the Clean Air Act addressed the problem of visibility degradation. Congress directed Environmental Protection Agency to develop regulations aimed at remedying existing visibility impairment caused by man-made air pollutants and also at preventing future problems. This provision of the Clean Air Act is currently being invoked by the EPA in order to solve a visibility problem created by the giant coal-burning power plant, the Navajo Generating System. The facility supplies power to more than four million residential and business customers in Arizona, Nevada, and California, and in the process pumps 65,000 to 70,000 tons of sulfur dioxide into the atmosphere each year. It also creates thick haze in the Grand Canyon, reducing visibility considerably. Under an EPA agreement expected to be signed into law in Fall 1991, owners of the power plant are expected to install boiler scrubbing systems expected to reduce annual sulfur dioxide emissions by 90 percent at a total cost of 430 million dollars [5], or approximately 8,000 dollars per ton of sulfur dioxide eliminated [5]. Effective implementation of public policies intended to improve visibility will involve considerable costs to consumers. For example, substituting low sulfur coal for high sulfur or 'dirty' coal in power plants will increase electricity rates significantly. The Congressional Budget Office has estimated that the implementation of carbon charges (taxes on fuels in proportion to the amount of carbon dioxide they release) will cost the American economy about 100 billion dollars.

While the measurement of the cost of visibility improvement may be simple, the computation of benefits is less obvious. The benefits accruing from visibility improvement can be quite significant. The potential benefits are: improvements in transportation and related business activities, increases in recreational activities (recreational swimming, fishing, game attendance, recreational aviation, etc.). Other possible benefits are property value and rent increases resulting from good view, reductions in air pollution-related health problems, probable decreases in visibility-related accident rates, and saving in travel time. In this study we attempt to compute the benefits of visibility improvements in terms of probable reductions in non-fatal accident rates, probability of occurrence of fatal accidents, and travel time reductions in Cook County, Illinois, which includes Chicago.

VISIBILITY IMPROVEMENTS AND TRAFFIC ACCIDENTS

The automobile has become a way of life in industrialized societies. Closely associated with this fact is the annual increase in reported highway casualties in the major cities. In 1988 there were 49,000 motor-vehicle fatal accidents and 1.8 million disabling injuries in the United States, resulting in 113.0 billion dollars in lost wages, medical expenses, property damage and insurance costs [6]. These accidents could result from faulty vehicle designs, reckless driving habits, bad weather, and other attributes of motorists. One would expect that, *ceteris paribus,* improvements in vehicle designs, reductions in driving intensity, and good weather will reduce accident rates. In fact, safety regulations have assumed a one-to-one correspondence between ex-ante engineering estimates of the effects of safety devices on highway safety and what actually happens after the regulations go into effect.

In our model we assume that visibility improvements result directly from the implementation of industrial pollution abatement regulations.

Earlier highway accident studies, often conducted by highway engineers, have focussed on the effects of geometric designs on highway safety [7]. The assumption was that better road designs increased safety, measured in terms of gross reductions in accident/death rates. Gosh et al. [8] found that highway speed and traffic volumes have positive effects on highway casualties, while weather (measured in terms of average hours of sunshine per day) was found to have a negative effect on traffic casualties. That is, good weather decreases traffic safety. No firm explanations were offered for these findings.

COST MINIMIZATION MODEL OF TRAVEL DEMAND

The variables most frequently employed in traffic accident and travel demand studies are: speed, traffic volume, age, alcohol consumption, weather, safety regulations, vehicle weight, risk taking behavior (driving intensity, recklessness, etc.), income, and gasoline prices. In this study it is assumed that cost minimization is the major driving force behind the motorists' travel decisions.

Let us define an improvement in safety as a change in climatic conditions (including visibility), traffic volume, speed, driving behavior (etc.) that reduces the rate of traffic accidents. Economic efficiency requires that the cost of achieving a given level of safety be minimized. Let us assume that the motorist in effect computes the price of travel as a solution to the problem of minimizing the cost of travel, which includes vehicle operating costs and the costs of accidents. For given types of vehicles, road conditions, and weather, the most relevant variable under the control of the motorist is speed.

$$\mathrm{TRC} = \mathrm{UP(SP)} + \mathrm{OC} \tag{1}$$

where TRC is the travel cost, and UP(SP) represents unit price, as a function of speed, of accidents in terms of medical bills, work hours lost due to accidents, cost of damages to vehicle, etc., and OC represents the operating cost per mile. It is assumed that, up to the legal speed limit, the marginal cost of a vehicle mile decreases as speed increases (the coefficients of the 55 miles per hour speed limit in accident rate studies have been significant and negative [9, 10].

The probability of an accident occurring at any given speed

$$\mathrm{PAC} = \mathrm{PAC}\,(\mathrm{VIS}, \mathrm{RC}, \mathrm{SP}, \mathrm{TV}, \mathrm{O}) \tag{2}$$

where VIS = visibility (visual range in miles)
RC = road conditions (rain, snow, ice, etc.)
SP = speed (measured in miles per hour)
TV = traffic volume
O = other relevant variables

The minimization of travel cost implies that

$$\frac{d(\mathrm{UP} \cdot \mathrm{PAC})}{d\mathrm{SP}} = \frac{d(\mathrm{OC})}{d\mathrm{SP}} \tag{3}$$

The choice of speed to minimize travel cost implies that at the point of travel cost minimization the marginal savings in operating cost (the right side of Equation 3) must be equal to the marginal expected increase in the cost of an accident (the left side).

From Equation 2 the total effect of improvement in visibility on the probability of occurrence of accidents is

$$\frac{d(PAC)}{d(VIS)} = \frac{\partial PAC}{\partial SP}\frac{d(SP)}{d(VIS)} + \frac{\partial(PAC)}{\partial(VIS)} + \frac{\partial((PAC)}{\partial(TV)} \bullet \frac{d(TV)}{d(VIS)} \tag{4}$$

Let us assume that at constant speed the partial effect of improvement in visibility on the probability of accidents, $\frac{\partial(PAC)}{\partial(VIS)}$ is negative. $\frac{\partial(PAC)}{\partial(SP)}$ which measures the partial effect of speed on probability of accidents, is positive, i.e., speed increases the probability of occurrence of an accident. The third term on the right side of Equation (4) measures the effect of visibility on accident probability through its influence on traffic volume.

Ceteris paribus, the partial effect of traffic congestion on the probability of accidents is assumed to be positive. The partial effect of visibility improvement on traffic congestion $\frac{\partial(TV)}{\partial(VIS)}$ is ambiguous. From Equation 4, the total effect of improvements in environmental visibility on the probability of occurrence of an accident is also ambiguous. It depends on the relative magnitudes of the components of Equation 4. Hence we cannot conclude *a priori* that environmental regulations which decrease the levels of pollutants and therefore improve visibility will decrease the probability of occurrence of an accident.

Peltzman [11] demonstrates that although technological studies predict that safety regulations lead to accident reductions, this gain could be completely offset by drivers' response to increased safety. He contrasts a model of driver utility maximation choice of safety inputs in which he assumes that the typical driver faces a choice (similar to the choice between leisure and money income) between driving intensity and probability of death from an accident. Safety regulation lowers the risk of driving intensity and the probability of death if an accident occurs. However, if driving intensity is a normal good we should expect a higher probability of death after regulation. Peltzman's results showed that safety regulation resulted in reduction in the probability of accidents but increased the deaths per accident. That is, accident severity increased after safety regulations, thereby offsetting any gains from safety regulations.

Using time series data, Crandall and Graham [10] show that although we can expect some offsetting behavior, the behavioral responses triggered by market forces are overwhelmed by intrinsic engineering effects of safety devices [10]. The evidence is that the magnitude of the offset is an empirical issue.

DATA SOURCES AND THE STATISTICAL MODEL

Data on the number of fatal and non-fatal accidents were collected in Cook County from January 1978 to June 1980 on a daily basis. Visibility data, measured in terms of miles of visual range, were collected from O'Hare Airport. Additional data were collected from the O'Hare Weather Station on the occurrence of snow, fog, rain, as well as the daily temperature recordings in degrees F.

The mean daily visibility in Cook County was 10.3 miles. The average fatal accident rate was 0.42 per day while the average number of daily non-fatal accidents was 194.3.

We specify a linear reduced-form model in which the daily occurrence of non-fatal accidents in Cook County (CCNONFAT) is a function of weekday/weekend dummy variables, seasonal dummies, visibility level and other weather variables (rain, snow, fog, temperature):

$$\text{CCNONFAT} = f(\text{DD, WTR, SUMR, SPR, VIS, VIS}^2\text{, DVD, VWTR, VSPR, VSUM, RA, SN, FG, VTEM, VRA, TEM}) \tag{5}$$

DD equals 1 if the accident occurred on weekdays and equals 0 otherwise; WTR, SUMR, SPR represent 1/0 dummy variables for winter, summer, spring; VIS represents visibility in miles; RA equals 1 for the occurrence of any of the following on the day the accident occurred; rain, rain showers, freezing rain, drizzle, and 0 otherwise.

SN (snow) and FG (fog) are also represented by dummy variables. DVD measures the effect of the interaction between visibility and the day of week (DD) while the interactions between visibility and the seasonal dummies and other weather variables are similarly defined. It is assumed that visibility captures some of the effects of speed and traffic congestion on non-fatal accident rates.

If we formulate a model with fatal accidents as the dependent variable most of the values will be zeros and ones. This suggests the use of a binary choice (discrete choice) model in analyzing the occurrence/non-occurrence of fatal accident rates in Cook County. The simplest kind of binary choice model is the Linear Probability Model (LPM) where it is assumed that the probability of occurrence/non-occurrence of a fatal accident on any given day is a linear function of the explanatory variables in Equation (5). The dependent variable CCFATAL = 1 if fatal accident was recorded for the day and zero, otherwise. We must thus interpret the dependent variable as the effects of a unit change in the explanatory variables on the probability of occurrence of fatal accidents [12].

RESULTS AND DISCUSSION

The parameter estimates of the OLS regression model are presented in Table 1. The elasticity of non-fatal accidents with respect to visibility improvements equals 0.800, implying that 10 percent increase in visibility decreases non-fatal accidents

Table 1. Cook County Non-Fatal Accidents OLS Regression Results

	Dependent Variable: CCNOFAT	
Variable	Parameter Estimate	T Ratio
Intercept	387.55	9.77
DD	48.27	4.18
WNTR	60.37	2.48
SUMR	22.77	0.87
SPR	56.72	2.44
VIS	−15.63	−3.25
VIS2	0.026	0.16
DVD	−0.72	−0.71
VWTR	4.82	2.36
VSPR	2.96	1.57
VSUM	2.17	1.02
RA	46.73	3.33
SN	63.15	3.84
FG	−10.88	−1.15
VTEM	0.148	3.06
VRA	−0.027	−0.02
VSN	−4.11	−2.07
TEM	−2.35	−4.17

PR > F = 0.0001
R^2 = 0.35
DW = 1.39

by 8 percent. Most of the coefficients in Table 1 are quite precisely estimated. Non-fatal accidents increased by 60 units in winter and 57 units in spring compared to the base season (fall). Although the summer variable is imprecisely estimated, it has the right sign. Tolley et al. [13] report that on the average visibility is lower in summer in the US by 2 to 3 miles, compared to the other seasons [13]. But speed and traffic volume increase in summer contributing to increased accident rates.

Our linear reduced-form model of non-fatal accidents and the linear probability model of fatal accidents in Cook County show that an improvement in visibility by one mile in Cook County leads to a decrease in non-fatal accidents of 15.6 while increasing the probability of fatalities by 0.023 (see Table 2). This later result is due to the offsetting behavior by motorists. The partial effect of visibility improvement is to increase fatal accidents in summer relative to fall. However, the interactions between visibility and the seasonal dummy variables show that improvements in visibility cause fatal accidents to decrease in winter and spring but increase in summer relative to fall.

Table 2. Linear Probability Model of Traffic Fatalities in Cook County

	Dependent Variable: CCFATAL	
Variable	Parameter Estimate	T Ratio
Intercept	–0.059	–0.215
DD	0.026	1.928
WNTR	0.258	2.473
SUMR	–0.062	–1.319
SPR	0.180	1.041
VIS	0.023	1.979
DVD	0.009	2.080
VWTR	–0.022	–1.417
VSPR	–0.020	–1.353
VSUM	0.003	0.181
RA	0.008	0.075
SN	0.037	0.289
FG	–0.047	–0.801
VTEM	–0.0002	–0.659
VRA	–0.02	–0.147
VSN	0.004	0.250
TEM	0.006	1.534

PR > F = 0.0059
R^2 = 0.41
DW = 1.932

In his critique of Peltzman's model, Macavoy suggests that an elaborate simultaneous model which treats some of the determinants of accident rates (for example, speed and volume) as endogenous variables is more appropriate [14]. As an alternative to the linear reduced-form model of non-fatal accidents a system of simultaneous equations was formulated to explain the occurrence of accidents. Volume and speed were modelled as endogenous variables which depend on visibility, road conditions and weather [15]. The results showed that the elasticities of speed and non-fatal accidents with respect to visibility improvements are 0.0684 and -0.4397. That is a 10 percent improvement in visibility (by 1.03 miles from an average of 10.3 miles) will directly increase speed by 0.684 percent (by 0.34 miles per hour) and decrease non-fatal accidents by 4.3 percent.

We conclude that a 10 percent improvement in visibility decreases non-fatal accident rates by 15.6 units per day (using estimates from Table 1). However, if speed and traffic volume are modeled as endogenous variables then a 10 percent increase in visibility decreases non-fatal accidents by 8.4 units per day (the elasticity is reduced from 0.80 to 0.68 when speed and volume are considered as endogenous variables).

BENEFIT VALUATION

In this section we shall attempt to value the benefits accruing to Cook County of a policy which improves visibility by 10 percent. In valuing the reduction in non-fatal accidents we make use of data on the social cost of a non-fatal accident computed by Fagan [16]. The cost of non-fatal accident is made up of loss in wages, medical expenses, property damage, legal fees and insurance administration costs. The total cost in 1988 prices is $7,000 per non-fatal accident. An improvement in visibility by 10 percent in Cook County reduces non-fatal accidents by 15.6 units per day, saving $109,200 per day or 39.9 million dollars per annum (1988 prices).

The fatal accidents model showed that an improvement in visibility by one mile, which is approximately equal to a 10 percent improvement, increases the probability of fatalities by 0.023 per day. The daily fatal accident rate in Cook County is 0.42. The expected number of fatal accidents per day is 0.0097 or 3.54 fatalities per annum. In estimating the cost of lives lost we make use of value of life estimates provided by Thaler and Rosen [17]. We use an estimate of $700,000 (1988 prices) for the value of human life. The 3.54 fatalities represent a cost of 2.5 million dollars. The annual value of the reduction in non-fatal accidents less the cost of the increase in fatal accidents in Cook County equals 37.4 million dollars in 1988 prices.

A final component of benefits from visibility improvement is the value of time saved by current road users and the value of extra trips made as a result of visibility improvement. We know that the elasticity of speed with respect to visibility equals 0.0684 = β [15]. The time saved due to improvement in visibility by one mile by current road users = $\frac{-\beta}{\text{VIS} \times \text{SP}} \times$ Wage rate; we have to compute this value for buses, trucks and automobiles.[1] The total value of time saved equals

$$\frac{-\beta}{\text{VIS} \times \text{SP}}\left(W_{bd} \times N_{bd} + \frac{1}{2} W_{oc} + W_{td} \times N_{td} + \frac{1}{2} W_{auto} \times N_{auto}\right),$$

[1] If $\frac{d(\text{miles/hr})}{d(\text{VIS})} \times \frac{\text{VIS}}{\text{miles/hr}} = \beta$, then

$$\frac{d(\text{hrs/mile})}{d(\text{VIS})} \times \frac{\text{VIS}}{\text{hrs/mile}} = -\beta;\ \text{therefore}$$

time saved =

$$\frac{d(\text{hrs/mile})}{d(\text{VIS})} = -\beta \frac{[\text{hrs/mile}]}{\text{VIS}} = \frac{-\beta}{\text{VIS} \times \text{SP}}$$

Data on private cars and busses were obtained from Mr. Larry Anderson of the Chicago Transportation Authority. Data on trucks and truck drivers were obtained from Mr. Gerald Rawling of the Chicago Area Transportation Studies. Figures are in 1986 prices.

where

W_{bd} = daily wages of a bus driver = 144 dollars (8 hrs. per day at $18 per hr.)

W_{oc} = a passenger's daily wages = 112 dollars (8 hrs. per day at $14 per hr.)

W_{td} = a truck driver's daily wages = 100 dollars (8 hrs. per day at 12.5 dollars per hr.)

W_{auto}= daily wages of automobile owners = $112 (8 hrs. per day at $14 per hr.)

N_{bd} = Number of bus drivers per day = 6741 (2247 buses per day with an average of 3 drivers per bus)

N_{oc} = Number of bus riders per day = 800,000

N_{td} = Number of working truck drivers per day = 36,554

N_{auto} = Number of people using personal cars per day = 800,000

Substituting the figures shown into the value of time saved equation yields 3.62 million dollars per annum for the City of Chicago (1986 prices) or 2.8 million dollars in 1988 prices for the City of Chicago, which is about 5 million dollars for Cook County.

The aggregate benefits of a 10 percent improvement in visibility in Cook County equal 42.4 million dollars per annum. This includes the annual value of reduction in non-fatal accidents (39.9 million dollars), less the annual cost of an increase in fatal accidents (2.5 million dollars), plus the value of time saved by current road users (5 million dollars).

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