Safety Externalities of SUVs on Passenger Cars: An Analysis Of the Peltzman Effect Using FARS Data

By David R. Martinelli, Ph.D., and Maria-Paulina Diosdado-De-La-Pena

West Virginia University

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n Passenger
FARS Data

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, several issues have been raised. In 2003, Dr.
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Safety Externalities of SUVs on Passenger Cars: An Analysis of the Peltzman Effect Using FARS Data

David R. Martinelli, PhD.
Maria-Paulina Diosdado-De-La-Pena

Department of Civil and Environmental Engineering
Morgantown, West Virginia
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ABSTRACT

Safety Externalities of SUVs on Passenger Cars: An Analysis of the Peltzman Effect Using FARS Data

Maria-Paulina Diosdado-De-La-Pena

In the last decade, Sport Utility Vehicles (SUVs) have become a considerable percentage of the US vehicular fleet, giving rise to several highway safety issues such as: vehicular incompatibility, rollover propensity and offsetting driver behavior. While greater mass, stiffness and dimensions of SUVs relative to passenger cars, are safety advantages of SUVs, they may encourage SUV drivers to engage in a trade off between this new level of safety and risk taking behavior, named Peltzman Effect.

In this research a model developed by Levitt and Poter (2001) for drinking drivers is applied to assessing the Peltzman Effect of SUVs and Passenger Cars with a set of data characteristics to control for preexisting risk taking behavior. It was found that indeed SUVs pose an externality hazard on passenger cars and that SUV drivers are 2.7 times more likely to cause a fatal crash compared to passenger cars.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

In 2005, the National Center for Health Statistics (NCHS) reported 2,448,017 deaths in the U.S., of these 43,510 happened in motor vehicle crashes (Fatality Analysis Reporting System, FARS). Every year, around 42,700 people are killed in motor vehicle crashes (Table 1.1), which occur in roughly 38,400 fatal crashes (Table 1.2).

Several factors lead to the occurrence of fatal automobile crashes. These factors fall into three general classifications: the driver, the road, or the vehicle, and in some extreme cases, a combination of them. Mostly, the driver is the source in the form of behavior, driving error, or physical condition.

Often it is assumed that driver behavior is shaped by age, sex, and marital status, among other characteristics. In recent years, there has been a broad variety of vehicle types, makes, and models to suit a diversity of needs. One prominent vehicle feature is vehicle body type, providing not only a trend in terms of sales but also some behavioral characteristics could be inferred from the buyer.

In particular, one body vehicle type has emerged as highly popular among U.S. motorists, namely; the Sport Utility Vehicle (SUV). According with the Bureau of Transportation Statistics (BTS), SUV sales have grown from only 183,000 in 1980 to 4,515,000 in 2008 (Table 1.3)

This dramatic SUV ownership has raised several safety issues over the years, including: regarding the, fleet incompatibility, SUVs safety, and rollover propensity, hazards associated with interaction with smaller vehicles, offsetting driver behavior, and gasoline mileage.

Table 1.1 Motor vehicle crash fatalities per year (Source, FARS)

Year	2006	2005	2004	2003	2002	2001	2000
Total Fatalities	42,642	43,510	42,836	42,884	43,005	42,196	41,945

Table 1.2 Fatal motor vehicle crashes (Source, FARS)

Year	2006	2005	2004	2003	2002	2001	2000
Fatal Motor Vehicle Crashes	38,588	39,252	38,444	38,477	38,491	37,862	37,526

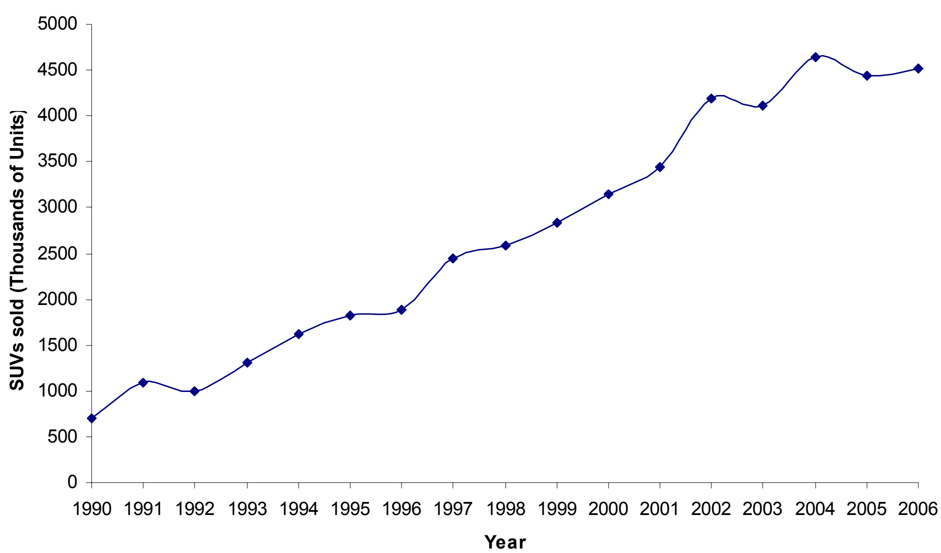

Figure 1.1 SUVs sold 1990-2006

(Source, Bureau of Transportation Statistics)

Table 1.3 Sport Utility Vehicles Sold 1980-2006 (Source, Bureau of Transportation Statistics)

	Year																		
Thousands of Units Sold	1980	1985	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Small SUV	60	115	189	136	129	144	188	189	120	489	316	314	400	390	354	264	338	172	104
Midsize SUV	100	563	447	904	799	1038	1265	1397	1528	1401	1623	1762	1863	1944	1802	2093	2318	2161	2440
Large SUV	23	57	72	54	75	129	169	230	241	560	642	754	879	1115	2034	1760	1992	2109	1971
T O T A L	183	735	708	1094	1003	1311	1622	1816	1889	2450	2581	2830	3142	3449	4190	4117	4648	4442	4515

1.2 Problem definition

Based on BTS data, it can be stated that there has been a considerable increase of SUVs presence in the U.S. vehicle fleet. This change has introduced two main safety issues: 1) vehicle incompatibility and 2) offsetting driver behavior. It is refer by vehicle incompatibility to the different vehicle characteristics as mass, stiffness and dimensions (Gabler and Hollowell, 1998) that provide uneven protection for the vehicles involve in case that a motor vehicle crash occurs (Abdelwahab and Abdel-Aty, 2004).

A common justification of ownership among SUV drivers is the increased (or perceived increase) in safety achieved through additional weight, stronger suspension, and higher seating position. This may lead to a false sense of security among SUV drivers that may result in driving behavior that could pose increased risks among conventional automobiles. This offsetting driver behavior is known as the Peltzman Effect, where consumers of a good (in this case SUVs) pose an externality on non-users (in this case conventional automobiles).

The main issue is to determine if SUVs drivers take greater risks, and translating this risk to occupants of non-SUVs passenger car occupants. By looking at only the overall death rates, misleading results maybe obtained because a confounded effect between vehicle incompatibility and diver behavior is very likely to exist. While more deaths are expected to occur in passenger cars due to a structural disadvantage relative to SUVs, it is expected that SUV drivers may have different driver behavior patterns. This is why it is necessary to develop a method that separates the effect of SUV driver behavior from that of the vehicle physical configuration and characteristics.

1.3 Objective of the project

The main objective of this project is to determine if SUV drivers pose safety externalities on passenger cars, due to an assumed SUV driver offsetting behavior (Peltzman effect). To accomplish this objective it is necessary compete the following stages,

1) To review the different crash characteristics aspects between SUVs in car crashes as driver and vehicle characteristics, available crash data, and Peltzman effect through a comprehensive literature review.
2) To extend existing models of driver behavior to apply to SUVs drivers.
3) To determine the desired data set characteristics and to select the data in function of those considerations.
4) To apply an appropriate model to the selected data set.
5) To interpret the parameters obtained from the previous stage and determine if indeed SUVs drivers are more dangerous than the passenger car drivers, and the statistical significance of those results.

2. LITERATURE REVIEW

2.1 Sport Utility Vehicle Characteristics

Bradsher (2002) considers that there is not a formal definition for SUV, and points that most governmental agencies group SUVs within the category of “Light Trucks”, which may be and advantage for vehicle manufacturers since less regulations concerning safety gas mileage, and air pollution may apply (Plaut, 2004). Due to a somewhat vague classification, Bradsher proposed five features that define as SUVs those that,

1) As standard or optional equipment of four-wheel drive;
2) Have an enclosed rear cargo area (similar to the minivan cargo area);
3) Are characterized by a high ground clearance for off-road travel purposes;
4) Are built on a pickup-truck underbody;
5) Are mainly designed and marketed for urban consumers through, a comfortable suspension.

A broader description is provided by the American National Standard Institute in the “Manual on Classification of Motor Vehicle Traffic Accidents” (1996), where a utility vehicle encompasses the following,

1) It is a motor vehicle, other than a motorcycle or bus, designed for transporting at most ten people;
2) Usually has four-wheel drive and an increase ground clearance to achieve off-road capabilities;
3) Its gross vehicle weight rating is 10,000 pound or less;
4) It could be sub-classified as
    - Mini (Wheelbase is less or equal than 88 inches).
    - Small (Wheelbase is greater than 88 inches, and overall width is less or equal than 66 inches).

- Midsize (Wheelbase is greater than 88 inches, and overall width is greater than 66 inches but less than 75 inches).
- Full-size (Wheelbase is greater than 88 inches, and overall width is greater or equal than 75 inches but less or equal than 80 inches).
- Large (Wheelbase is greater than 88 inches, and overall width is greater than 80 inches).

Two SUV characteristics noted above are particularly relevant to this study. First, they are narrower and higher than other motor vehicles which could lead to higher rollover potential, and therefore driver injury. Nevertheless, this might be mitigated by their greater mass and consequently crashworthiness (Khattak and Rocha, 2003). Second SUVs have greater structural stiffness, since in general, a stiff frame rail is used instead of unibody (which is a softer design) of passenger cars (Gabler and Hollowell, 1998).

2.2 SUVs' Driver Characteristics

Several studies have been conducted to explain driver characteristics as they relate to vehicle body type. One study established that several aspects such as travel attitude, personality, and lifestyle are strong factors affecting vehicle type choice, and in the case of SUVs drivers, these factors were characterized as a free-spirit attitude (Choo and Mokhtarian, 2004).

Plaut (2004) examined SUV commuters' characteristics within the framework of light trucks, through the analysis of the 2001 American Housing Survey, particularly Journey-to-Work data to determine socio-demographic characteristics. The findings of the study were that,

1) SUV owners take longer trips; in terms of distance an average of 2.4 miles more and referring time, an average of 1.98 minutes more than car commuters;
2) SUV owners are more likely to have college education than car commuters, but less likely to hold postgraduate degrees;
3) SUV owners have incomes that are higher, but their household income is lower than car commuters;
4) SUV owners surprisingly, own fewer motor vehicles than car commuters.
5) SUV owners are more likely to live close to green areas than urbanized areas, than car commuters.
6) SUV owners tend to live in rural areas within the MSA, or completely outside the MSA .

2.3 Fatality Analysis Reporting System

The National Center for Statistics and Analysis (NCSA) of the National Highway Traffic Safety Administration (NHTSA) created the Fatality Analysis Reporting System (FARS) in 1975 with the idea of providing a quantitative tool to assess the safety of the U.S. highway network. The agencies specifically, address issues such as traffic safety problems and the evaluation of special motor vehicle and highway safety programs. FARS includes data from fatal traffic crashes within 50 States, the District of Columbia, and Puerto Rico. For a crash to be considered in this dataset it must occur in a traffic way open to the public and as a consequence, the death of one of the people involved in the crash within the next 30 days. Among the information gathered for FARS are the crash, vehicle, driver, and person forms (NHTSA and NCSA, "*Fatal Crash Data Overview Brochure*).

The crash form includes information regarding the number of fatalities in the crash, number of vehicle forms submitted, date, atmospheric conditions, and location where it occurred. The vehicle form includes body type, number of occupants, number of fatalities, travel speed, vehicle year, model and make. The driver form mainly data about driver license compliance and restrictions, previous DUIs and previous traffic violations. The person form gathers the characteristics of the persons involved in the crashes such as age, alcohol presence, injury severity suffered, sex, seating position and person type.

2.4 Related Studies

Based on the premise that a significant amount of fatalities occur in crashes involving a light truck or a van (LTV) Gabler and Hollowell (1998) performed a study to determine if indeed LTVs were more likely to cause more fatalities due to their design through the quantification of the vehicle aggressivity in a parameter named "Aggressivity Metric" (AM), which is the ratio of driver fatalities in the opposite vehicle to the number of crashes were a specific vehicle body type was involved. It is important to emphasize that the number of crashes was selected in order to separate the confounding issue between aggressive vehicle design and aggressive driver behavior, since they were interested only in the aggressive vehicle design. The findings state that, in general, LTVs are more aggressive than passenger cars. In general, the most aggressive vehicle is found to be full-size vans with an AM equal to 2.47. SUVs ranked in the third place (just after full-size pickups) as the most aggressive vehicles with AM=1.91, followed by small pickups, minivans, large cars (AM=1.15), midsize car, compact car and finally subcompact cars (AM=0.45).

Abdelwahab and Abdel-Aty (2004) analyzed the effect of the increase in LTVs as it may increase head-on traffic crashes, concluding that by 2010 there will be an increase of 8% in head-on collision fatalities, however, the increment of LTVs will not affect the total head-on collisions. However, as a consequence of the growth LTV from 1995-2003, the probability of two-LTV crashes will increase, increasing the likelihood of death for the occupants of the both LTVs.

Khattak and Fan (2008) focused on the effect of driver and roadway factors that accentuate vehicular incompatibility, traducing it in physical and monetary harm. Essentially, they assigned dollar values to crash injuries and established a technique to include property damage and social cost of such crashes. Finally, the average cost of harm to passenger cars and occupants is almost two times higher than SUVs, assigning $78,932 for passenger cars and $39,737 for SUVs. With these findings, it is assessed the road incompatibility between SUVs and passenger cars.

Gayer (2007) was concerned about regulatory differences between light trucks and passenger cars. Based on regionalized FARS data, he analyzed the problem by estimating the relative crash frequencies for SUVs, vans, pickups and passenger cars only in summer months since the crash frequency increases in winter months due to snow. The study handled the bias selection posed by FARS data through weighting fatal two-car crashes with the number of pedestrians fatalities, since given a set of assumptions it is believed that through this method it is possible to represent the total number of crashes (fatal and non-fatal). He concluded that light trucks are more likely to crash (2.63-4.00) than passenger cars.

2.5 The Peltzman Effect

It was 1966 when the “National Traffic and Motor Vehicle Safety Act” was signed by President Lyndon Johnson. This Act was the milestone in vehicle safety improvement that enacted mandatory safety devices such as seat belts, energy-absorbing steering columns, penetration-resistant windshields, dual braking systems, and padded instrument panels (Peltzman, 1975). Based on these introduced changes, Sam Peltzman raised the question about the efficiency of those mandatory safety regulations in his study *“The Effects of Automobile Safety Regulation”* (1975). The available literature at that time expected an initial death rate reduction between 10% and 25%.

The study established the relationship between “Driving Intensity”, which is the driver willingness to take risk, with the “Probability of Death to Driver” as a positive slope curve. The consequence of the mandatory safety devices was a decrease in the slope curve, meaning, that for a given “Driving Intensity” the probability of death would decrease in comparison to the original curve; nevertheless, this could not be ensured since “Driving Intensity” is a normal good and the curve might be elastic (Peltzman, 1975).

The aforementioned conduced Peltzman to plant the possibility that the new “Driving Intensity” equilibrium might be higher for the same “Probability of Death to Driver”, yielding to higher pedestrian risk (and to other non vehicle occupants) since these two variables are paired (Peltzman, 1975).

After analyzing the crash rates before the regulation year, projecting crash rates for regulated years as unregulated, and comparing these to the actual regulated crash rates, he concluded that auto safety regulation did not change the highway death rate. In general, safety regulation did decrease the probability of death for drivers, but this is offset by involving themselves in a riskier behavior, which reassigns the change of deaths from vehicle occupants to pedestrians (Peltzman, 1975).

However, the Peltzman study was confronted by others like Roberson (1977), who believed that indeed pedestrian deaths remained at the same rate, and that Peltzman’s conclusion was misleading by improperly aggregating fatality rates.

One strong point proposed by Winston et al. (2006) was that a confounded effect between automobile safety regulation and driver type may exist in aggregate datum studies, such as Robertson (1977). Their study was based on airbags and antilock brakes, since these were gradually introduced to the vehicle market before being required by law. This approach is fundamental, since the consumers freely acquired them and adjust their driving patterns and behavior to the new vehicle features. The study was based on Washington State data, analyzing “injury” severity levels concluding that offsetting behavior takes place when denominated “safety-conscious” drivers purchase airbags and antilock brakes, and their benefits are diminished by their consumption of intensity (Winston et al., 2006). In this way, the Peltzman effect determined earlier was validated.

This offsetting behavior has also been studied in Canada focusing on the effect produced by seat belt legislation with data collected by the Traffic Injury Research Foundation (TIRF). In this database, fatalities are recorded as a function of person type, as driver, passenger, or pedestrian. It was concluded that mandatory seat belt use may be responsible for an 18 to 21% decrease in driver ant vehicle occupant fatalities and that pedestrian fatalities remain at the original level. Nevertheless, one of the points that served to approve the mandatory seat belt use was an expected driver death reduction of 29%, which lends support to the presence of offsetting behavior (Sen, 2001), since this death reduction was not achieved.

Traynor (1993) was aware of the lack of a model that directly analyzed driver behavior through isolation and varying safety conditions, leading to a model that considers the safety level environment and driver characteristics through binary variables for each one of these. The conclusion of the study was supportive for the offsetting behavior theory.

Another outstanding study on the Peltzman effect theory was developed by Sobel and Nesbit (2007) using NASCAR crash data. One appealing characteristic of using NASACR crash data is that there are no aggregation data issues, like those present in state and nation-wide databases. Besides, there is a certain level of repeatability since there is control over the weather, track and vehicle conditions. They found that NASCAR drivers engage in an offsetting behavior (a more reckless driving) when the safety standards are raised.

Regarding SUV drivers, Ulfarsson and Mannering (2004) concluded that possible behavioral differences appear as risk compensation resulting from the apparent SUV safety with respect to size, weight and higher driving position.

3. MODEL AND DATA SELECTION

3.1 Problem similarities with the drinking drivers' analysis of Levitt and Poter

Levitt and Poter (2001) conducted a study to determine if drinking drivers represented a hazard for sober drivers. They addressed two main problems; first it is impossible to know for a given time how many drinking and sober drivers are on the road. Because of this, it is unfeasible to obtain a parameter that indicates the relative fatal crash risk of drinking versus sober drivers. The second issue was that the studies conducted to establish the percentage of drinking drivers on the road through random roadblocks and driver stops have serious drawbacks, such as the high costs required to perform them, and also, the drivers selected cannot be forced to submit to alcohol tests.

Given the aforementioned circumstances, they decided to use only fatal crash data (FARS), since the frequency of two-car fatal crashes involving driver configurations such as sober/sober, drinking/drinking and, sober/drinking contain valuable information. Mainly, two-car fatal crashes 'opportunities' follow a binomial distribution, which means that two-car fatal crashes involving two sober drivers is proportional to the square of the number of sober drivers. The same applies for two drinking drivers, and for drinking/sober drivers is linearly proportional to the number of sober and drinking drivers on the road (Levitt and Potter, 2001). This removes the concern of not knowing the real exposure or total crash opportunities since only fatal crashes are analyzed.

In the particular case of SUV drivers, it is possible to know how many SUVs are registered on the U.S. motor vehicle fleet, however, that does not mean that all those SUVs are on the road at the same time. Which lead also to the same scenario that Levitt and Potter faced.

3.2 Assumptions of the model

The following description establishes the five assumptions developed by Levitt and Potter (2001) for the drinking/sober drivers model, these are adjusted to the corresponding scenario of SUVs and passenger cars drivers.

Assumption 1. There are two types of drivers for this case: drivers of SUVs (T) and drivers of Passenger Car (P). By this, the total number of drivers is $N_{TOTAL} = N_T + N_P$. Restricting the drivers to only two categories not only yields a more understandable model, similar to that developed by Levitt and Potter, but also confine the study to the motor vehicle types that are of real concern for this project.

Assumption 2. There is “equally mixing” of SUV and Passenger Car drivers over time and space. This means that the amount of interactions that a driver encompasses is independent of the motor vehicle body type that he or she is driving. Also, the driver’s types which he or she interacts are independent of his or her own driver’s type. Considering the variable *I* equal to 1 if two cars interact and zero otherwise, this summarizes as;

$$\Pr(i|I=1) = \frac{N_i}{N_T + N_P} \tag{1}$$

$$\Pr(i, j|I=1) = \Pr(i|I=1)\Pr(j|I=1) \tag{2}$$

Assumption 3. The blame of a resulting crash is only related to one of the drivers,

Assumption 4. The composition of driver types in one fatal crash dies not affected the driver composition of other fatal crashes.

3.3 Model deduction

Once the assumptions of the model were established, Levitt and Poter (2001) the next three steps in connecting the FARS data to the parameters of concern,

1) To determine the likelihood that two cars will interact,
2) To determine the likelihood of a crash occurrence given two types of drivers and an interaction happens between them,
3) To establish the likelihood function.

It is important to remember that the following is an adaptation of Levitt and Potter (2001) model to the particular case of SUV and Passenger Car drivers.

Based on the assumption 2, and particularly equation (1) and (2), it is possible to derive the joint distribution for a pair of driver types *i* and *j* , conditional on an interaction *I* between them,

$$\Pr(i, j|I=1) = \Pr(i|I=1)\Pr(j|I=1)$$

$$\Pr(i, j|I=1) = \left(\frac{N_i}{N_T + N_P}\right)\left(\frac{N_j}{N_T + N_P}\right)$$

$$\Pr(i, j|I=1) = \frac{N_i N_j}{(N_T + N_P)^2} \quad (3)$$

Applying the previous likelihood function when SUV/SUV, P/P and SUV/P drivers interactions occur,

$$\Pr(T, T|I=1) = \frac{{N_T}^2}{(N_T + N_P)^2} \quad (4)$$

$$\Pr(P, P|I=1) = \frac{{N_P}^2}{(N_T + N_P)^2} \quad (5)$$

$$\Pr(T, P | I = 1) = \frac{N_T N_P}{(N_T + N_P)^2} \quad (6)$$

Now, in order to continue with the model derivation, a variable *C* is defined as one if a fatal crash occurs and zero otherwise. It is known that for a crash to occur, first an interaction between two vehicles must happen and then one of the drivers must make a fatal mistake (Levitt and Poter, 2001), remember that the driver making the mistake is the responsible for the crash. This term is very important, it is a *crash* since the fault of this event is attainable to one of the drivers and it could be avoided, and is not an *accident*, because an accident implies no fault to the individuals involve. With this statement and going back to assumption 3, the probability of a crash to occur given that two drivers interact on the road is directly related to their probability of making a mistake,

$$\Pr(C = 1 | I = 1, i, j) = \theta_i + \theta_j - \theta_i \theta_j \approx \theta_i + \theta_j \quad (7)$$

The term $\theta_i \theta_j$ is eliminated from the function for two reasons, in Assumption 3 it is established that fault is only assigned to one of the drivers and, Levitt and Potter (2001) mathematically determined that this value is exceptionally minuscule, translating θ_i and θ_j to mean values.

The probability of a fatal crash with two specific driver types given and interaction between them is established by the joint probability of multiplying equations (3) and (7),

$$\Pr(i, j, C = 1 | I = 1) = \frac{N_i N_j}{(N_T + N_P)^2} (\theta_i + \theta_j) \quad (8)$$

An important attribute rises from the data over which the model will be applied, this is FARS data contains only fatal crashes. Because on that, the previous equation has to be altered to read "given a fatal crash" instead of "given an interaction,"

$$\Pr(i, j|C=1) = \frac{\Pr(i, j, C=1|I=1)}{\Pr(C=1|I=1)}$$

$$\Pr(i, j|C=1) = \frac{N_i N_j (\theta_i + \theta_j)}{2\left[\theta_T (N_T)^2 + (\theta_T + \theta_P) N_T N_P + \theta_P (N_P)^2\right]} \quad (9)$$

The previous equation in terms of SUV/SUV, SUV/P and P/P driver configurations is,

$$P_{TT} = \Pr(i=T, j=T|C=1) = \frac{\theta_T (N_T)^2}{\left[\theta_T (N_T)^2 + (\theta_T + \theta_P) N_T N_P + \theta_P (N_P)^2\right]} \quad (10)$$

$$P_{TP} = \Pr(i=T, j=P|C=1) = \frac{(\theta_T + \theta_P) N_T N_P}{\left[\theta_T (N_T)^2 + (\theta_T + \theta_P) N_T N_P + \theta_P (N_P)^2\right]} \quad (11)$$

$$P_{PP} = \Pr(i=P, j=P|C=1) = \frac{\theta_P (N_P)^2}{\left[\theta_T (N_T)^2 + (\theta_T + \theta_P) N_T N_P + \theta_P (N_P)^2\right]} \quad (12)$$

One issue here is that there are four unknown parameters θ_P, θ_T, N_P, and N_T, and only three equations are available to solve this system (11-13). This was solved by Levitt and Potter using ratios for the parameters instead of the individual ones,

$$\theta = \frac{\theta_T}{\theta_P} \quad (13)$$

$$N = \frac{N_T}{N_P} \qquad (14)$$

In this way, *θ* represents the relative likelihood that a SUV driver causes a fatal crash compared to a Passenger car driver in a two-car crash. If the value of *θ* is less than one, this would mean that SUV drivers are less likely to make a mistake that causes a fatal crash compared to Passenger car drivers. If the value is equal to one, it means that both have the same probability of making a fatal mistake. And finally, if *θ* is greater than one, it would indicate that SUV drivers have a higher probability of making a fatal mistake, and consequently, a higher probability of causing a fatal crash.

And the new ratio N is the number of SUV drivers over the number of Passenger Car drivers over a specific geographical area and time. Applying the ratios *θ* and *N* in equations 10-12,

$$P_{TT}(\theta, \mathrm{N}|C) = \frac{\theta N^2}{\theta N^2 + (\theta + 1)N + 1} \qquad (10)$$

$$P_{TP}(\theta, \mathrm{N}|C) = \frac{(\theta + 1)N}{\theta N^2 + (\theta + 1)N + 1} \qquad (11)$$

$$P_{PP}(\theta, \mathrm{N}|C) = \frac{1}{\theta N^2 + (\theta + 1)N + 1} \qquad (12)$$

There is independence across fatal crashes (Assumption 4), the joint distribution of driver types follows the multinomial distribution (Levitt and Potter, 2001), and since all the individual probabilities for the different driver type's configurations are established, it is possible to derive the likelihood function of the model,

$$\Pr(C_{TT}, C_{TP,} C_{PP}|C_{TOTAL}) = \frac{(C_{TT} + C_{TP} + C_{PP})!}{C_{TT}!C_{TP}!C_{PP}!}(P_{TT})^{C_{TT}}(P_{TP})^{C_{TP}}(P_{PP})^{C_{PP}} \qquad (13)$$

In a practical manner, it is obvious that the maximum likelihood estimate of crashes involving two specific types of drivers is just the fraction of those driver type configurations with respect to all the fatal crashes, which means,

$$\hat{P}_{TT} = \frac{C_{TT}}{C_{TOTAL}} \tag{14}$$

$$\hat{P}_{TP} = \frac{C_{TP}}{C_{TOTAL}} \tag{15}$$

$$\hat{P}_{PP} = \frac{C_{PP}}{C_{TOTAL}} \tag{16}$$

It is desired to determine the relative crash risk of SUV and Passenger Cars exclusively based on the observed fatal crash distribution, this encourages the search for a ratio which allows it. By the binomial distribution, it is known that the squared of the interactions SUV/PC is in fixed proportion to the product of SUV/SUV and PC/PC (Levitt and Poter, 2001), this is obtained through,

$$\frac{(C_{TP})^2}{C_{TT}C_{PP}} = \frac{\left(\frac{(\theta+1)N}{\theta N^2+(\theta+1)N+1}\right)^2}{\left(\frac{\theta N^2}{\theta N^2+(\theta+1)N+1}\right)\left(\frac{1}{\theta N^2+(\theta+1)N+1}\right)}$$

$$\frac{(C_{TP})^2}{C_{TT}C_{PP}} = \frac{(P_{TP})^2}{P_{TT}P_{PP}} = \frac{[(\theta+1)N]^2}{\theta N^2} = \frac{(\theta+1)^2 N^2}{\theta N^2} = \frac{(\theta+1)^2}{\theta} = \frac{\theta^2+2\theta+1}{\theta} = \theta+2+\frac{1}{\theta} \tag{17}$$

If the previous equation is equaled to a variable named R,

$$R \equiv \frac{(C_{TP})^2}{C_{TT}C_{PP}}$$

Then,

$$R \equiv \theta + 2 + \frac{1}{\theta}$$

$$R - \theta - 2 = \frac{1}{\theta}$$

$$R\theta - \theta\theta - 2\theta = 1$$

$$R\theta - \theta\theta - 2\theta - 1 = 0$$

$$-\theta^2 - (2 - R)\theta - 1 = 0$$

$$\theta^2 + (2 - R)\theta + 1 = 0 \qquad (18)$$

The solution roots of equation (18) can be found through,

$$\theta = \frac{-(2-R) \pm \sqrt{(2-R)^2 - 4}}{2} = \frac{(R-2) \pm \sqrt{4 - 4R + R^2 - 4}}{2} = \frac{(R-2) \pm \sqrt{R^2 - 4R}}{2} \qquad (19)$$

In conclusion, knowing C_{TT}, C_{TP} and C_{PP} in a specific geographical area and time, R can be computed, N and ultimately θ, which is the value of interest.

The standard error for the maximum likelihood estimation can be determined based of the Hessian matrix, which is the matrix of second partial derivatives of the model likelihood function (Appendix A).

$$Hessian = \begin{bmatrix} \frac{\partial^2 \Pr}{\partial \theta^2} & \frac{\partial^2 \Pr}{\partial \theta \partial N} \\ \frac{\partial^2 \Pr}{\partial N \partial \theta} & \frac{\partial^2 \Pr}{\partial N^2} \end{bmatrix} \qquad (20)$$

The corresponding variance is,

$$Var = -[Hessian]^{-1} \qquad (21)$$

Finally, the standard error can be computed by obtained the squared root of the diagonal elements of the variance matrix divided by the sample size minus one, for *θ* and *N*.

$$\sigma_\theta = \sqrt{-\frac{\frac{\partial^2 \Pr}{\partial N^2}}{\left[\left(\frac{\partial^2 \Pr}{\partial \theta^2} \times \frac{\partial^2 \Pr}{\partial N^2}\right) - \left(\frac{\partial^2 \Pr}{\partial \theta \partial N} \times \frac{\partial^2 \Pr}{\partial N \partial \theta}\right)\right](C_{TT} - 1)}} \tag{22}$$

$$\sigma_N = \sqrt{-\frac{\frac{\partial^2 \Pr}{\partial \theta^2}}{\left[\left(\frac{\partial^2 \Pr}{\partial \theta^2} \times \frac{\partial^2 \Pr}{\partial N^2}\right) - \left(\frac{\partial^2 \Pr}{\partial \theta \partial N} \times \frac{\partial^2 \Pr}{\partial N \partial \theta}\right)\right](C_{TT} - 1)}} \tag{23}$$

3.4 Scope and limitations of the model

By adapting the Levitt and Potter (2001) model to the particular case of crashes involving SUVs and Passenger Cars, it can be determined if a different behavior is developed on the studied driver types through *θ*. However, this offsetting behavior cannot be completely separated of preexisting driver characteristics. For the particular case of SUV drivers, the simple purchase of the vehicle *may* demonstrate a pre-existing tendency towards higher risk behavior.

3.5 Data characteristics

The model developed by Levitt and Potter (2001) was developed considering FARS data characteristics; this project also focuses on this database. The first step was examining the FARS data at nationwide level, and pulling out only the records belonging to drivers of two-car crashes.

One fundamental assumption of the model is that homogeneity is demanded in space and time in order to work properly. This means that not only areas with same characteristics have to been bounded, but also period of times when the economic and social factors do not affect significantly the driving patterns.

In order to take care of the space homogeneity constraint, the model is applied independently in six areas,

1) Mid-Atlantic States
2) Mid-West States
3) New England States
4) South States
5) Texas (Two cases)
6) West Coast States

Over these regions, the major Metropolitan Statistical Areas (MSA) were selected, always trying to built clusters or corridors areas (Appendix B). Since one of Plaut (2004) findings was that SUV owners have a tendency to live in rural areas within MSA. In this way a balanced presence of SUVs is warranted. Besides, it was desirable to create these clusters to get a convenient sample size. Also, by using MSAs it is more likely to have homogeneity in terms of preexisting driver risk taking level.

With respect to time homogeneity, it was established that a period of three years would be an appropriate approach, this also serves to warrant enough crashes involving two SUV drivers. The periods are 1995-1997, 1996-1998, 1997-1999, 1998-2000, 1999-2001, 2000-2002, 2001-2003, 2002-2004, 2003-2005, and 2004-2006. Some periods are not available for all regions. Those are indicated subsequently.

Finally, there were concerns about what impact alcohol presence would have in the results. To avoid a confounding effect between driver offsetting behavior and drinking drivers, only crashes that occurred on Monday, Tuesday, Wednesday, Thursday and Friday between 6:00 and 17:59 hours were analyzed, since there is a lower presence of drinking drivers is expected during those times.

Also, it is important to mention that this time restriction allows focusing in a more homogeneous population in terms of risk taking behavior regardless of the vehicle body type driven. It is a common belief that there are certain times of the day the drivers engage in a more reckless driving.

3.6 Selected data

Applying the criteria established in section 3.4, the fatal crashes selected were those,

1) Were two cars were involved,
2) The two driver records were available and complete,
3) Occurred between 6:00 and 17:59 hours,
4) Took place Monday, Tuesday, Wednesday, Thursday or Friday, and
5) Happened on the states and counties specified in Appendix B.

The following tables are summaries of the fatal two-crashes that fulfilled those selection criteria,

Table 3.6.1 Mid-Atlantic Region Two-Car Fatal Crashes

Period	Fatal Crashes for Driver Type Configuration			
	P/P	P/SUV	SUV/SUV	Total
1995-1997	344	120	5	469
1996-1998	335	135	4	474
1997-1999	327	128	6	461
1998-2000	306	132	4	442
1999-2001	280	125	6	411
2000-2002	265	140	4	409
2001-2003	260	144	7	411
2002-2004	264	162	6	432
2003-2005	247	166	8	421
2004-2006	212	166	13	391

Table 3.6.2 Mid-West Region Two-Car Fatal Crashes

Period	Fatal Crashes for Driver Type Configuration			
	P/P	P/SUV	SUV/SUV	Total
1995-1997	348	97	0	445
1996-1998	328	85	0	413
1997-1999	304	78	0	382
1998-2000	289	88	2	379
1999-2001	291	102	7	400
2000-2002	281	129	7	417
2001-2003	280	150	9	439
2002-2004	233	157	6	396
2003-2005	225	151	12	388
2004-2006	200	134	11	345

Table 3.6.3 New England Region Two-Car Fatal Crashes

Period	Fatal Crashes for Driver Type Configuration			
	P/P	P/SUV	SUV/SUV	Total
1995-1997	94	27	1	122
1996-1998	85	30	1	116
1997-1999	76	38	3	117
1998-2000	65	37	4	106
1999-2001	58	36	3	97
2000-2002	62	31	1	94
2001-2003	68	30	1	99
2002-2004	66	32	2	100
2003-2005	62	42	2	106
2004-2006	59	50	2	111

Table 3.6.4 South Region Two-Car Fatal Crashes

Period	Fatal Crashes for Driver Type Configuration			
	P/P	P/SUV	SUV/SUV	Total
1995-1997	357	77	0	434
1996-1998	358	102	2	462
1997-1999	342	120	5	467
1998-2000	312	139	6	457
1999-2001	274	139	6	419
2000-2002	249	140	8	397
2001-2003	232	129	11	372
2002-2004	223	135	12	370
2003-2005	232	159	15	406
2004-2006	221	184	20	425

Table 3.6.5 Texas Two-Car Fatal Crashes (Case 1. Table)

Period	Fatal Crashes for Driver Type Configuration			
	P/P	P/SUV	SUV/SUV	Total
1995-1997	101	35	1	137
1996-1998	102	39	1	142
1997-1999	101	39	1	141
1998-2000	92	41	1	134
1999-2001	84	42	2	128
2000-2002	74	47	1	122
2001-2003	62	62	2	126
2002-2004	61	62	3	126
2003-2005	57	62	6	125
2004-2006	55	55	8	118

Table 3.6.6 Texas Two-Car Fatal Crashes (Case 2. Table)

Period	Fatal Crashes for Driver Type Configuration			
	P/P	P/SUV	SUV/SUV	Total
1995-1997	117	40	1	158
1996-1998	118	45	1	164
1997-1999	116	43	1	160
1998-2000	104	49	2	155
1999-2001	96	51	3	150
2000-2002	91	60	2	153
2001-2003	81	75	4	160
2002-2004	84	71	5	160
2003-2005	75	71	8	154
2004-2006	71	61	8	140

Table 3.6.7 West Coast Region Two-Car Fatal Crashes

Period	Fatal Crashes for Driver Type Configuration			
	P/P	P/SUV	SUV/SUV	Total
1995-1997	345	128	1	474
1996-1998	324	131	3	458
1997-1999	319	135	5	459
1998-2000	287	154	9	450
1999-2001	281	183	12	476
2000-2002	280	190	16	486
2001-2003	309	191	18	518
2002-2004	293	181	21	495
2003-2005	274	181	19	474
2004-2006	238	185	18	441

4. RESULTS

In general terms, when analyzing the New England States (Figure 4.3) and West Coast Region (Figure 4.7), it was found that the number of fatal crashes involving P/P drivers have been decreasing, P/SUV drivers has been increasing and, SUV/SUV has remained relatively stable over the last ten years, but for 2000-2002 and 2001-2003 the trend was the opposite for P/P and P/SUV.

For the Mid-Atlantic (Figure 4.1) and South regions (Figure 4.4), there is a clear pattern of decreasing numbers of P/P, and an increase of SUV/P fatal crashes; also fatal crashes involving two SUV drivers remain at a constant and low level.

For the Mid-West region (Figure 4.3), an important development is found: , there is a decreasing trend of P/P and an increasing trend in P/SUV, while SUV/SUV fatal crashes stay at a flat rate. However, it seems that an equilibrium is reached after 2002-2004, since the two curves are almost parallel to each other.

An a particular trend happened in Texas Case 1 (Figure 4.5) where the decreasing trend of P/P fatal crashes is overtaken by a significant increase in SUV/P fatal crashes and at the intervals 2001-2003 to 2003-2005 there are more SUV/P than P/P fatal crashes.

In conclusion, for all the regions studied, during the last 11 years there has been a decreasing trend in the number of two-car crashes involving two passenger car drivers. The opposite has happened to the P/SUV fatal crashes, and for SUV/SUV fatal crashes there has not been a change in the crash rates.

By itself, the previous analysis is week, but it raises several interesting questions,

1) Are the decreasing patterns in P/P fatal crashes attainable to safer passenger cars design in later years?

2) Are the increasing trends in P/SUV crashes due to the increase in the number of SUVs in the motor vehicular fleet?, or perhaps, there are more records of these in fatal crashes because of the physical disadvantage that passenger cars have against SUVs?, or is indeed an offsetting behavior which is causing this trend?
3) If the trend in P/SUV crashes is due to a higher percentage of SUVs in the motor vehicle fleet, it would also significantly raise the SUV/SUV fatal crashes regardless of the higher safety that these provide for their occupants. Why is this not the case?

For finding answers to those questions, it is necessary to analyze the results of the model.

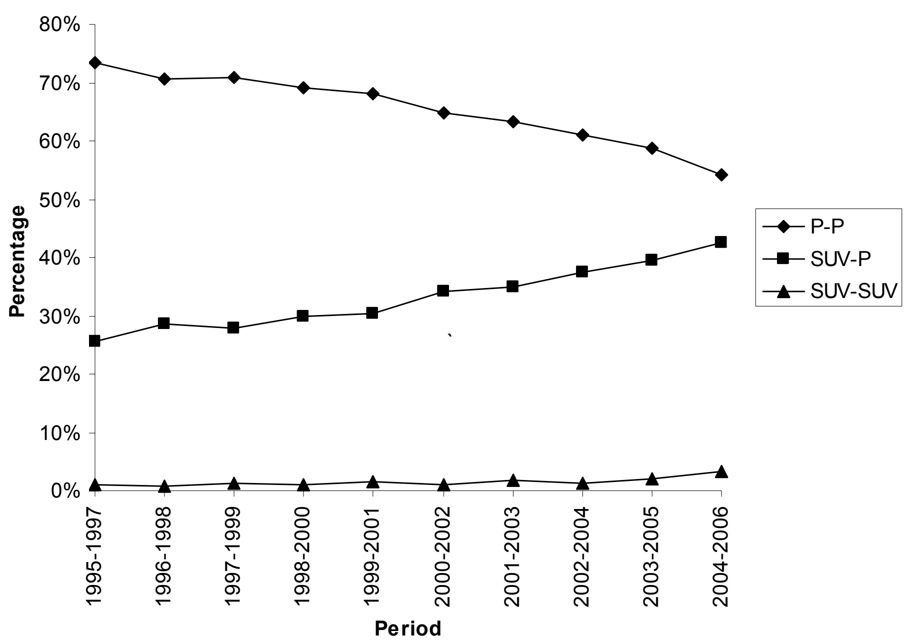

Figure 4.1 Mid-Atlantic Region Fatal Crash Trends