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Decomposing the Danger of Drinking Drivers: 1983-2012

Richard A. Dunn

Nathan W. Tefft

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UNIVERSITY OF CONNECTICUT

Charles J. Zwick Center for Food and Resource Policy
Department of Agricultural and Resource Economics
College of Agriculture and Natural Resources
1376 Storrs Road, Unit 4021
Storrs, CT 06269-4021
Phone: (860) 486-2836
Fax: (860) 486-1932
ZwickCenter@uconn.edu
www.zwickcenter.uconn.edu

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Richard A. Dunn
University of Connecticut

Nathan W. Tefft
Bates College

Abstract:
This paper estimates the relative risk of drunk-drivers causing a fatal accident using imputed values for BAC from the Fatality Analysis Reporting System for three time periods. In addition, we develop an econometric approach that allows the decomposition of fatal accident risk into two components: the relative probability of a drunk-driver causing a serious accident and the probability of dying in a serious accident. Our results suggest that the relative risk of drunk drivers causing a fatal accident increased by approximately one-third from 1983-1993 to 2004-2013. Further, the increase in relative risk was caused almost entirely by an increase in the relative risk of drunk drivers causing a serious accident. In contrast, the relative risk of a drunk driver dying in a serious accident was nearly unchanged. We also find that there has been a decrease in the incidence of drunk driving, as well as the external cost associated with drunk-driving.

Keywords
drunk-driving, motor vehicle fatality, externality, FARS

I. Introduction

There were 10,322 alcohol-impaired driving fatalities in the United States during 2012, accounting for roughly 31% of all motor-vehicle related fatalities (NHTSA, 2013). Alcohol consumption increases the risk of causing a motor vehicle crash, endangering the lives of other drivers, cyclists, and pedestrians (Anda, Williamson, & Remington, 1988; Borkenstein, Crowther, & Shumate, 1974; Corrao, Bagnardi, Zambon, & Arico, 1999; Fabbri et al., 2001; Levitt & Porter, 2001; Lund & Wolfe, 1991; Taylor et al., 2010; Taylor & Rehm, 2012; Zador, Krawchuk, & Voas, 2000). The external costs associated with drunk driving are one of the primary motivations for public policies aimed at reducing the incidence of driving after consuming alcohol. Identifying the relative risk of drunk drivers is thus required to calculate the optimal penalty to driving while intoxicated (Pigouvean tax) and determine the cost-effectiveness of policy interventions.

Levitt and Porter (2001) demonstrate that both the fraction of drunk-drivers and their relative risk of causing a fatal crash can be identified using information about the blood alcohol content (BAC) of drivers involved in fatal two-car accidents. This is a valuable insight as studies that rely on random traffic stops, such as the National Roadside Survey (NRS) (Lund & Wolfe, 1991; Voas, Wells, Lestina, Williams, & Greene, 1998; Zador, 1991; Zador et al., 2000), can suffer from sample selection bias as drivers likely to be the most inebriated will be the least likely to submit to a voluntary BAC test. Applying their result to data on two-vehicle fatal crashes from 1983 to 1993, they estimate that drivers with BAC above 0.10 are 13 times more likely to cause a fatal accident, significantly smaller than the relative risk estimated by Zador (1991) and Zador, Krawchuk and Voas (2000) based on NRS results. Applying a value of a statistical life of $3 million, Levitt and Porter (2001) calculate a Pigouvean tax rate of 30cents per mile driven or $8,000 per arrest to fully internalize the externality.

Although their findings continue to be widely cited in the drunk-driving literature, their analysis utilizes data that is now over two decades old. During that time period, there have been significant advances in automobile technology, including the widespread adoption of airbags[1] and the introduction of electronic stability control systems[2], as well as improvements in road design.[3] The role of consumer electronics in the automobile have also changed dramatically since their study period. Mobile phones and complex entertainment systems have presented drivers with additional distractions, while GPS navigation systems allow many drivers to focus more on traffic and worry less about finding their destination. To the extent that these changes asymmetrically influence to probability of surviving a motor vehicle accident based on the inebriation level of drivers, the relative risk drunk-drivers impose to sober drivers could be very different today. For example, air bags that automatically deploy upon impact reduce fatality risk more among drivers and passengers who are wearing a seatbelt (Braver, Ferguson, Greene, & Lund, 1997; Cummings, Koepsell, Rivara, McKnight, & Mack, 2002). If sober drivers were

[1] The first patents for airbag technology were issued to Walter Linderer (Germany #896,312) and John Hetick (US #2,649,311) in 1953. But, it was not until 1989 that Chrysler became the first automaker to include driver-side airbags as standard equipment in all US domestic models. The Intermodal Surface Transportation Act of 1991 mandated that driver-side and passanger-side airbags would be standard offered in all automobiles produced after September 1, 1998.

[2] Electronic stability control (ESC) compares the intended direction of travel (the rotation of the steering wheel) with the actual direction of travel (yaw). When these are sufficiently different, brake pressure is applied asymmetrically to each wheel, generating torque and thereby correcting the loss of steering control. The earliest commercial versions of ESC systems were introduced in the United States as optional features in luxury vehicles by BMW in 1997 (standard in all models by 2001) and Mercedes-Benz in 1997 (standard in all models by 2000) (Dang, 2004). Federal Motor Vehicle Saftegy Standard (FMVSS) 126 mandated that ESC be a standard feature in all new automobiles produced after September 1, 2011 with the phase-in period beginning September 1, 2008.

[3] The Safe, Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA) was signed into law on August 10, 2005, establishing the Highway Safety Improvement Program (HSIP) to reduce accident fatalities and injuries through infrastructure-related highway safety improvements.

more likely to wear seat belts, this technology would have a greater impact on the fatality rate of sober drivers.

Moreover, the data available to drunk-driving researchers has changed significantly. When Levitt and Porter conducted their analysis, a large percentage of drivers involved in fatal motor vehicle accidents were not administered a test to determine BAC. This introduces a serious concern about potential selection of drivers into their sample.[4] Since that time, the proportion of drivers killed in a fatal motor vehicle accident who are tested to determine BAC has increased from 54% in 1982 to 68% in 1997 to 76% in 2008 (Hedlund, Ulmer, Northrup, 2004; Cassanova, Hedlund and Tilson, 2012). For surviving drivers, the proportion has increased from 16% in 1982 to 26% in 1997 to 29% in 2008 (Hedlund, Ulmer, Northrup, 2004; Cassanova, Hedlund and Tilson, 2012). Furthermore, researchers at the Department of Transportation have developed a multiple imputation strategy to accommodate missing BAC values in FARS that can be applied to all available incident reports from 1982 onward (Subramanian, 2002).

Given these changes in both driving technology and the available data, this paper applies the Levitt and Porter (2001) methodology (hereafter LP) to estimate the relative risk of drunk-drivers in a more recent FARS sample period using imputed values for BAC where measured values are unavailable. Across a number of model specifications, our results suggest that the *relative* risk of drunk to sober drivers increase significantly over the past three decades. While the relative risk of drinking to non-drinking drivers decreased by 12.3 percent from the 1983-87 period to the 2008-2012 period, the relative risk of drunk drivers increased 30.5%.

[4] Because of this issue, Levitt and Porter (2001) based much of their analysis on police officer reports of whether they believed the driver(s) involved in the accident had consumed alcohol.

To explore the causes that potentially explain this change in fatal accident risk, we extend the LP method by decomposing the risk of causing a fatal accident into two parts: the risk of causing a serious accident and the risk of a driver dying in a serious accident. The original LP method only utilizes information about the driver types involved in two-car fatal accidents, discarding other useful information about the accident. We demonstrate how information about the number of drivers killed in a fatal accident and the drinking status of deceased drivers provides identification of other risk parameters. We find that the increase in relative risk is explained entirely by a higher relative probability of drunk drivers causing a serious accident, increasing from 6.1 between 1983 and 1993 to 8.2 between 2004 and 2011. In contrast, the relative risk of a drunk driver dying in a serious motor vehicle accident was nearly unchanged: increasing slightly from 2.34 to 2.36.

II. Identifying fatal accident risk

This section briefly summarizes the identification argument developed by Levitt and Porter (2001) and employed in the subsequent analysis to identify the relative risk of drunk drivers causing a fatal motor vehicle accident. Let there be two types of drivers, drunk (*D*) and sober (*S*), with N_D and N_S denoting the number of each operating a vehicle within a given geographic area and time period. Assume that both the number of interactions a driver has with other vehicles (passing in the same or opposite direction, following or leading, meeting at an intersection, etc) and the composition of the drivers encountered is independent of driver type (equal mixing). Then, the probability of interacting with a driver of type *i* conditional on an interaction occurring is $Pr(i|I=1)=N_i/(N_D+N_S)$ and the probability of a driver of type *i* interacting with a driver of type *j* is simply the product of these probabilities: $Pr(i,j|I=1)=N_iN_j/(N_D+N_S)^2$. Further assume that a fatal accident occurs when a driver makes a fatal error, θ_i, the likelihood of which depends upon driver type.[5] Thus, the probability that a fatal accident occurs when a driver of type *i* interacts with a driver of type *j* is $Pr(A=1|I=1, i, j)=\theta_i+\theta_j+\theta_i\,\theta_j$. As the chance of a fatal accident occurring with any given interaction between vehicles is extremely small, the final term can be safely ignored, so that $Pr(A=1|I=1, i, j)\approx\theta_i+\theta_j$.

The probability of an accident between drivers of type *i* and *j* is:

$$\Pr(A, i, j|I = 1) = \Pr(A|I = 1, i, j)\Pr(i, j|I = 1) = \frac{N_i N_j(\theta_i + \theta_j)}{(N_D + N_S)}$$

Notice that $Pr(A=1|I=1, i, j)= Pr(A=1|I=1)\, Pr(i, j\ |A=1)$ so that:

$$\mathrm{P_{ij}} = \Pr(\,i, j|A = 1) = \frac{N_i N_j(\theta_i + \theta_j)}{2[\theta_D(N_D)^2 + (\theta_D + \theta_S)N_D N_S + \theta_S(N_S)^2]}$$

These four probability expressions yield two linearly independent equations in four unknowns: N_D, N_S, θ_D and θ_S.[6] Let $N=N_D/N_S$ denote the ratio of drunk drivers to sober drivers and $\theta=\theta_D/\theta_S$ denote the relative risk of drunk drivers. Then, the probabilities of observing the three different combinations of driver types in a fatal two-vehicle accident are:

$$\mathrm{P_{DD}} = \frac{\theta N^2}{\theta N^2 + (\theta + 1)N + 1}$$

$$\mathrm{P_{DS}} = \frac{(\theta + 1)N}{\theta N^2 + (\theta + 1)N + 1}$$

$$\mathrm{P_{SS}} = \frac{1}{\theta N^2 + (\theta + 1)N + 1}$$

[5] Allowing for heterogeneity within driver type, θ_i is the mean fatal error probability for drivers of type *i*.
[6] The equations for P_{SD} and P_{DS} capture observationally identical outcomes. Further, $P_{SS} + P_{DD} + 2P_{DS} = 1$. Thus, only two of the equations are linearly independent.

Assuming that the composition of drivers is independent across accidents, the joint distribution two-vehicle accidents characterized by driver type is mulitnomial:

$$\Pr(A_{DD}, A_{DS}, A_{SS}) = \frac{(A_{DD} + A_{DS} + A_{SS})!}{A_{DD}!\,A_{DS}!\,A_{SS}!}(P_{DD})^{A_{DD}}(P_{DS})^{A_{DS}}(P_{SS})^{A_{SS}}$$

where A_{ij} denotes the number of two-vehicle accidents involving a driver of type *i* and a driver of type *j*. Substituting the accident probabilities yields the likelihood function to be maximized. Doing so does not yield a unique solution, but further assuming that the relative risk of a drunk driver causing a fatal accident is greater than that of a sober driver is sufficient to determine θ.

III. Decomposing fatal accident risk

The method developed by Levitt and Porter utilizes the mix of driver types involved in fatal accidents to identify the relative risk of causing a fatal accident. This approach discards important information about fatal accidents that can be used to further decompose fatal accident risk. In this section, we demonstrate how the LP framework can be extended to recover both the risk of causing a serious accident and the risk of dying in a serious accident by incorporating information about the number of drivers who die in a two-car fatal accident and their alcohol status.

Maintaining the base assumption of equal mixing, the probability of a driver of type *i* interacting with a driver of type *j* is: $Pr(i,j|I=1)=N_iN_j/(N_D+N_S)^2$. Further assume that a serious accident occurs when a driver makes a serious error, σ_i, the likelihood of which depends upon driver type.[7] Thus, the probability that a serious accident occurs when a driver of type *i* interacts with a driver of type *j* is $Pr(A=1|I=1, i, j)=\sigma_i+\sigma_j-\sigma_i\,\sigma_j$. As the chance of a serious accident

[7] Allowing for heterogeneity within driver type, σ_i is the mean fatal error probability for drivers of type *i*.

occurring with any given interaction between vehicles is extremely small, the final term can be safely ignored, so that $Pr(A=1|I=1, i, j) \approx \sigma_i+\sigma_j$.

The probability that both drivers are killed when a serious accident occurs is:

$$Pr(death_i=1,death_j=1|A=1, i, j)=Pr(death_j=1|death_j=1, A=1, i, j)Pr(death_i=1|A=1, i, j)=\delta_i\delta_{j|i}.$$

Similarly, one can write the probability that driver *i* is killed, but driver *j* survives as:

$$Pr(death_i=1,death_j=0|A=1,i, j)=Pr(death_j=0|death_j=1, A=1,i, j)Pr(death_i=1|A=1,i, j)=\delta_i(1-\delta_{j|i}).$$

The probability of a serious accident between drivers of type *i* and *j* that kills both drivers is:

$$\begin{aligned}
&\Pr\left(A, death_i = 1, death_j = 1 | I = 1\right) \\
&\qquad = \Pr\left(death_i = 1, death_j = 1 | A = 1, i, j\right) \Pr(A|I = 1, i, j) \Pr(i, j|I = 1) \\
&\qquad = \frac{N_i N_j\left(\sigma_i + \sigma_j\right)\delta_i\delta_{j|i}}{(N_D + N_S)}
\end{aligned}$$

The probability of a serious accident between drivers of type *i* and *j* that kills driver *i* but not driver *j* is:

$$\begin{aligned}
&\Pr\left(A, death_i = 1, death_j = 0 | I = 1\right) \\
&\qquad = \Pr\left(death_i = 1, death_j = 0 | A = 1, i, j\right) \Pr(A|I = 1, i, j) \Pr(i, j|I = 1) \\
&\qquad = \frac{N_i N_j\left(\sigma_i + \sigma_j\right)\delta_i(1 - \delta_{j|i})}{(N_D + N_S)}
\end{aligned}$$

Similarly, the probability of a serious accident between drivers of type *i* and *j* that kills driver *j* but not driver *i* is:

$$\Pr\big(A, death_i = 0, death_j = j \mid I = 1\big)$$

$$= \Pr\big(death_i = 0, death_j = 1 \mid A = 1, i, j\big) \Pr(A \mid I = 1, i, j) \Pr(i, j \mid I = 1)$$

$$= \frac{N_i N_j \big(\sigma_i + \sigma_j\big) \delta_j (1 - \delta_{i|j})}{(N_D + N_S)}$$

Let *F=1* denote an accident that causes a driver fatality and d_i=1 denote that a driver of type *i* was killed. Within subset of FARS data that includes two-vehicle accidents in which at least one driver is killed, we can define four interaction types: {(*drunk*, *drunk*); (*drunk*, *sober*); (*sober*, *drunk*); (*sober*, *sober*)} and three driver outcomes, {(*death*, *death*); (*death*, *survive*); (*survive*, *death*)} for a total of 12 fatal accident types. Of course, some combinations are observationally equivalent, e.g., (*drunk-death, sober-death)=(sober-death, drunk-death)*. Thus, there are 7 observable accident types: (*drunk*, *drunk*, *2 deaths)*; (*sober, sober*, *2 deaths)*; (*drunk*, *sober*, *2 deaths)*; (*drunk*, *drunk*, *1 death)*; (*sober, sober*, *1 death)*; (*drunk-death*, *sober-survive)*; (*sober-death*, *drunk-survive*).

Applying Bayes' Rule, we thus have the following probabilities:

$$\mathrm{P}_{\mathrm{DD}}^{11} = \Pr(d_D = 1, d_D = 1 \mid F = 1) = \frac{2 N_D^2 \sigma_D \delta_D \delta_{D|D}}{\omega}$$

$$\mathrm{P}_{\mathrm{DS}}^{11} = \Pr(d_D = 1, d_S = 1 \mid F = 1) = \frac{N_D N_S (\sigma_D + \sigma_S) \delta_D \delta_{S|D}}{\omega} = \frac{N_D N_S (\sigma_D + \sigma_S) \delta_S \delta_{D|S}}{\omega}$$

$$\mathrm{P}_{\mathrm{SS}}^{11} = \Pr(d_S = 1, d_S = 1 \mid F = 1) = \frac{2 N_S^2 \sigma_S \delta_S \delta_{S|S}}{\omega}$$

$$\mathrm{P}_{\mathrm{DD}}^{10} = \Pr(d_D = 1, d_D = 0 \mid F = 1) = \frac{2 N_D^2 \sigma_D \delta_D (1 - \delta_{D|D})}{\omega} = \Pr(d_D = 0, d_D = 1 \mid F = 1)$$

$$\mathrm{P}_{\mathrm{DS}}^{10} = \Pr(d_D = 1, d_S = 0|F = 1) = \frac{N_D N_S(\sigma_D + \sigma_S)\delta_D(1 - \delta_{S|D})}{\omega} = \Pr(d_S = 0, d_D = 1|F = 1)$$

$$\mathrm{P}_{\mathrm{SD}}^{10} = \Pr(d_S = 1, d_D = 0|F = 1) = \frac{N_D N_S(\sigma_D + \sigma_S)\delta_S(1 - \delta_{D|S})}{\omega} = \Pr(d_D = 0, d_S = 1|F = 1)$$

$$\mathrm{P}_{\mathrm{SS}}^{10} = \Pr(d_S = 1, d_S = 0|F = 1) = \frac{2N_S^2\sigma_S\delta_S(1 - \delta_{S|S})}{\omega} = \Pr(d_S = 0, d_S = 1|F = 1)$$

$$\begin{aligned}\omega = {} & 2N_D^2\sigma_D\delta_D\delta_{D|D} + 2N_D N_S(\sigma_D + \sigma_S)\delta_D\delta_{S|D} + 2N_S^2\sigma_S\delta_S\delta_{S|S} + 2N_D^2\sigma_D\delta_D\left(1 - \delta_{D|D}\right) \\ & + N_D N_S(\sigma_D + \sigma_S)\delta_D\left(1 - \delta_{S|D}\right) + N_D N_S(\sigma_D + \sigma_S)\delta_S\left(1 - \delta_{D|S}\right) \\ & + 2N_S^2\sigma_S\delta_S(1 - \delta_{S|S})\end{aligned}$$

These probability expressions yield seven equations in ten unknowns. But again, because these probabilities must sum to unity, there are only six linearly independent equations. Thus, define the following ratios: $N = N_D/N_S$; $\sigma = \sigma_D/\sigma_S$; and $\delta = \delta_D/\delta_S$. We then have:

$$\mathrm{P}_{\mathrm{DD}}^{11} = \Pr(d_D = 1, d_D = 1|F = 1) = \frac{2N^2\sigma\delta\delta_{D|D}}{\widetilde{\omega}}$$

$$\mathrm{P}_{\mathrm{DS}}^{11} = \Pr(d_D = 1, d_S = 1|F = 1) = \frac{N(\sigma + 1)\delta_{D|S}}{\widetilde{\omega}}$$

$$\mathrm{P}_{\mathrm{SS}}^{11} = \Pr(d_S = 1, d_S = 1|F = 1) = \frac{2\delta_{S|S}}{\widetilde{\omega}}$$

$$\mathrm{P}_{\mathrm{DD}}^{10} = \Pr(d_D = 1, d_D = 0|F = 1) = \frac{2N^2\sigma\delta(1 - \delta_{D|D})}{\widetilde{\omega}} = \Pr(d_D = 0, d_D = 1|F = 1)$$

$$\mathrm{P}_{\mathrm{DS}}^{10} = \Pr(d_D = 1, d_S = 0|F = 1) = \frac{N(\sigma + 1)\delta(1 - \delta_{S|D})}{\widetilde{\omega}} = \Pr(d_S = 0, d_D = 1|F = 1)$$

$$\mathrm{P}_{\mathrm{SD}}^{10} = \Pr(d_S = 1, d_D = 0|F = 1) = \frac{N(\sigma + 1)(1 - \delta_{D|S})}{\widetilde{\omega}} = \Pr(d_D = 0, d_S = 1|F = 1)$$

$$\mathrm{P}_{\mathrm{SS}}^{10} = \Pr(d_S = 1, d_S = 0|F = 1) = \frac{2(1 - \delta_{S|S})}{\widetilde{\omega}} = \Pr(d_S = 0, d_S = 1|F = 1)$$

$$\widetilde{\omega} = 2N^2\sigma\delta + 2N(\sigma + 1)\delta_{D|S} + 2 + N(\sigma + 1)\delta(1 - \delta_{S|D}) + N(\sigma + 1)(1 - \delta_{D|S})$$

Finally, note that Bayes' rule provides a means of expressing δ as a function of conditional probabilities:

$$\delta_D\delta_{S|D} = \delta_S\delta_{D|S} \rightarrow \delta = \frac{\delta_{D|S}}{\delta_{S|D}}$$

Thus, we are able to identify seven model parameters: N, σ, δ, $\delta_{D|D}$, $\delta_{S|D}$, $\delta_{D|S}$, and $\delta_{S|S}$.

IV. Data

Data for the analysis come from the Fatality Analysis Reporting System (FARS), a nationwide census of fatal motor vehicles accidents compiled by the National Highway Traffic Safety Administration (NHTSA). FARS began operation in 1975 and continues to serve as a standard data source for studies of motor vehicle accidents, for example, Levitt and Porter (2001) utilize FARS data from 1983 through 1993.

But, a notable quality issue in the FARS data is the absence of measured BAC for many drivers involved in fatal accidents and the strong possibility of random selection of who is tested. In their baseline analysis, Levitt and Porter relied on the police officer's assessment of whether a driver had been drinking, and thus these estimates are based on the population of drinking drivers, not the population of drivers that are legally impaired. In a robustness check, they also consider drivers with tested BAC above 0.10, but only in states where at least 95% of drivers who were judged to be impaired by police officers are tested. The latter restriction, intended to reduce the influence of sample selection bias, eliminates almost 80% of their sample.

In 2002, the NHTSA adopted a multiple imputation strategy to accommodate missing BAC information (Subramanian, 2002) and provided imputed BAC levels for all existing FARS data back to 1982. It is thus possible to compare the estimation results of Levitt and Porter based on reported BAC with those attained through multiple imputation methods. It is also possible to provide updated estimated based on more recent FARS data from 1994 through 2012.

Table 1 provides descriptive statistics for the FARS data on crashes between 8:00 p.m. and 5:00 a.m. over three time periods, 1983-1993, 1994-2003, and 2004-2012, using both multiple imputation and subjective police-officer reports. As has often been reported in the literature, the annual number of fatal crashes has declined over time, and this trend is reflected in the average annual number of nighttime one- and two-car crashes across the three approximately decade-long periods. Drivers in fatal crashes were throughout all time periods disproportionately likely to be male, under the age of 25, and have a bad previous driving record, although the percentages declined over time. For example, more than half of all drivers in fatal accidents were male *and* drinking, and more than a quarter of all drivers in fatal accidents were under 25 and drinking between 1983 and 1993. The largest changes in the composition of drivers occurred between the 1983-1993 and 1994-2003 time periods, while the composition remained relatively stable between 1994-2003 and 2004-2012.

The bottom half of Table 1 reports percentages of one- and two-car accidents according to the drinking status of the involved drivers, where a driver is identified as “drinking” if his reported or average imputed BAC is greater than 0.02, and “non-drinking” otherwise. Similarly, a driver is identified as “legally drunk” if his BAC is greater than 0.1, and “sober” otherwise. Among one-car crashes, the percentages of non-drinking and sober drivers increased over time with the largest increases occurring between 1983-1993 and 1994-2003. Among two-car crashes, mixed drinking and non-drinking crashes hovered around 50% while the percentage of crashes with two non-drinking (drinking) drivers rose (fell) substantially. The percent of two-car crashes with two sober drivers rose by 14 points while mixed drunk/sober crashes fell by 10 points and two drunk driver crashes fell by 4 points.

Table 2 decomposes the subset of two-car fatal accidents in which there is at least one driver death. The number of such accidents has dropped steadily over time, from an annual rate of 3,260 between 1983 and 1993 to 2,341 between 2004 and 2011. Over those same periods, the proportion of two-car accidents in which both drivers die has fallen from six percent to five percent. Decomposing this change by the drinking status of drivers, the proportion of two-car accidents with two driver fatalities involving either one or two drunk drivers (BAC>0.1) has fallen, while the proportion with two sober drivers (BAC<0.1) increased. Similarly, the proportion of two-car accidents with two driver fatalities involving two drinking drivers (BAC>0.02) has fallen, while the proportion with two non-drinking drivers (BAC<0.02) increased.

The composition of two-car accidents in which one driver dies—94 to 95 percent of all two-car accidents that result in a driver fatality—has also changed over our study period. Between 1983 and 1993, 36.5 percent of fatal two-car accidents with one driver fatality involved two sober drivers; between 2004 and 2011 this figure increased to 50.6%. Over those same periods, the proportion of fatal two-car accidents with two drunk drivers and one driver fatality fell from 7.9 percent to 3.5 percent. A similar pattern exists when accidents are decomposed by drinking status. The proportion of fatal two-car accidents with one driver fatality involving two drivers who were not drinking increased, while the proportion of fatal two-car accidents with one driver fatality involving two drinking drivers decreased.

V. Results

Figure 1 depicts estimates of the relative risks of causing a fatal accident, over time, according to two driver groupings: drinking vs. non-drinking and legally drunk vs. sober. We restrict the sample to accidents that occur during peak drinking hours, i.e. between 8 p.m. and 4 a.m. Each graphed point represents a separate maximum likelihood estimation based on LP's model (described in section II) where equal mixing is assumed to occur at the year by hour by weekend level. In contrast to LP, we adopt the multiple imputation values provided by NHTSA for all time periods in order to mitigate concerns about selection and maintain a consistent approach across all periods. Estimation was feasible at the more granular five-year interval level, so we report those results in 95% confidence interval bands to display a clearer picture of the trends over time.

The relative risk of drinking to non-drinking drivers remained fairly stable over time, albeit decreasing somewhat from a maximum of 3.42 in 1983-1987 to 3.00 in 2008-2012, with a minimum of 2.50 in 1998-2002. This represents a 12.28% decrease in the relative risk from the first to last time period. The confidence interval bands in this case are also fairly tight, with all point estimates significantly greater than one.

It is worth discussing how our estimates differ from those of Levitt and Porter (2001), particularly for the time-period covered by their analysis: 1983-1993. For drinking drivers with equal mixing assumed at *hour x year x weekend*, LP estimate a relative risk of 5.14 (Table 2, column 4). Our estimates for 1983-1987 and 1988-1993 are roughly two-thirds as large. As the only difference in our approaches is the use of imputed driver BAC rather than police office reports of alcohol consumption, this suggests that Type I error upward biases the estimated risk of drinking drivers. This would be consistent with police officers assign drinking drivers with low BAC levels as non-drinking.

LP relax the equal mixing assumption further to *hour x year x weekend x state*, but we were unable to get the maximum likelihood procedure to converge at this level of disaggregation using quasi-newton methods. Nevertheless, we can utilize the results reported by LP as guidance as to how are estimated results would be affected. LP report that relative risk of drinking drivers is 7.51 when equal mixing is assumed at *hour x year x weekend x state*, a 46 percent increase when equal mixing is only applied at *hour x year x weekend*. Scaling our own estimate for drinking drivers by 46 percent implies that drinking drivers are 4.9 times more likely to cause a fatal accident.

In contrast to the decline in risk for drinking drivers, the relative risk of legally drunk to sober drivers *rose* substantially across the time period, from 5.81 in 1983-1987 to 7.58 in 2008-2012, with a peak of 8.57 in 2003-2007. This represents a 30.5 percent increase in the relative risk from the first to last period, with a 47.5 percent increase through the second-to-last. Here, the 95-percent confidence interval bands are estimated somewhat less precisely, presumably in part because of the relative sparseness of two-car accidents with two legally drunk drivers, but all estimates are again greater than one. That the trend in relative risk was not monotonically increasing and peaked around the time of the recession of 2007-2009 suggests that the relative risk of being legally drunk depends in part on conditions other than the differential effects of automobile safety technology changes on legally drunk vs. sober drivers.

LP only report relative risk for legally drunk drivers with equally mixing assumed at *hour x year x weekend x state*, thus our estimate for drunk drivers is not directly comparable. But, we can again use the estimates for drinking drivers to provide some guidance. Scaling our estimate under the assumption of equal mixing at *hour x year x weekend* by 46 percent implies that in the 1988-1993 period drunk drivers were at least 9.7 times more likely to cause a fatal accident. This is significantly smaller than the estimate of 13.2 reported by LP. Again, we suspect that this difference is a result of sample selection issues. To study the relative risk of drunk-drivers, LP excluded state-year pairs in which less that 95% of all drivers in fatal accidents were tested for BAC, eliminating the majority of FARS sample, potentially resulting in a sample that was not nationally representative. For example, if BAC testing was emphasized in states where drunk-drivers were most risky, then their estimate based on states with high testing rates would be larger than the national as a whole.

It is also possible to recover the proportion of legally drunk drivers using the following first-order condition from the likelihood function:

$$\theta \mathrm{N} = \left[\mathrm{A}_{\mathrm{DS}}\left(\frac{\theta}{1+\theta}\right) + \mathrm{A}_{\mathrm{DD}}\right] \Big/ \left[\mathrm{A}_{\mathrm{DS}}\left(\frac{\theta}{1+\theta}\right) + \mathrm{A}_{\mathrm{SS}}\right]$$

Figure 2 plots these calculated values using the accident percentages reported in the summary statistics and the scaled estimate of θ (1.46 times the coefficient reported in Figure 1). The proportion of legally drunk drivers on the road between 8pm and 5am has tended to decline over time from a high of 10.8 percent during the 1983-1987 period to a low of 5.5 percent between 2008 and 2012.

A. Decomposing accident risk

Table 3 presents maximum likelihood estimates of the relative risk of causing a serious accident, the relative risk of dying in a serious accident, and the marginal probabilities of one driver of type *i* dying conditional on a driver of type *j* dying based on two-car accidents in which at least one driver dies assuming equal mixing at the *year-hour-weekend* level. The relative risk of drinking drivers (BAC>0.02) causing a serious accident decreased from 3.4 between 1983 and 1993 to 2.5 between 1994 and 2003, but then increased to 3.2 between 2004 and 2011. In contrast, the relative risk of a drunk driver (BAC>0.1) causing a serious accident increased over time, rising slightly from 6.1 between 1983 and 1993 to 6.4 between 1994 and 2003, but then jumping to 8.2 between 2004 and 2011.

The relative risk of dying in a serious accident followed similar patterns regardless of whether drinking status or drunk status was used to reference driver types. The relative risk of drinking drivers dying in a serious accident initially increased from 2.0 between 1983 and 1993 to 2.4 between 1994 and 2003, then decreased to 2.1 between 2004 and 2011. Similarly, the relative risk of drunk drivers dying in a serious accident increased from 2.3 to 2.5, then decreased to 2.4.

Also of interest, the probability of a second driver dying in a fatal two-car accident depends on whether the other driver was drunk or sober. In each of the three periods examined, the probably that a sober driver will die in a two-car fatal accident is smaller if the deceased driver of the other vehicle was also sober. On the other hand, the probability that a drunk driver will die in a two-car fatal accident is larger if the deceased driver of the other vehicle was also drunk. This pattern was not observed when driver types were determined by drinking rather than drunk status.

Table 4 shows the impact of the equal mixing assumption on the estimated relative risk probabilities for the 2004-2011 period. As the equal mixing assumption is relaxed, the estimated relative risk of a drinking or drunk driver causing a serious accident increased, but has no effect on the estimated relative probability of death. Allowing equal mixing to vary by year tends to be less important than allowing it to vary by hour, weekend or state. (We cannot currently get state x hour x weekend to converge).

VI. The externality to drunk driving

In order to quantify the drunk driving externality, we calculated, relative to the counterfactual scenario in which all drunk drivers were instead sober, a) how many more accidents there are and b) how many extra lives would have been lost. In 2012 there were 7,671 accidents involving at least one drunk driver (with a BAC over 0.1). There were 33,561 fatalities due to all motor vehicle accidents, but only a subset of these fatalities are appropriately considered a result of drunk driving. We adopt the same assumptions as LP to count accidents and fatalities due to drunk driving externalities, including pedestrians who were killed by drunk drivers but who were themselves not drunk.

We tabulate the number of fatalities due to the external effects of drunk drivers using estimates on relative risk and the proportion of drunk drivers as reported in Figures 1 and 2. Note that the assumptions in producing these calculations are conservative in the sense that they are likely to yield underestimates of drunk driving externality. First, the "equal mixing" assumptions inherent in the maximum likelihood estimation model tend to underestimate the relative risks (Levitt and Porter, 2001). Second, the above tabulations only account for fatal accidents and do not count near-fatal or other non-fatal accidents. Third, we only calculate the externality with respect to legally drunk drivers (defined as having a BAC > 0.1) but under our hypothesis the externality begins accruing after the first sip of alcohol. Fourth, we calculate fatality benefits using value of statistical life (VSL) estimates (Viscusi, 1992) used by the U.S.

Department of Transportation (DOT, 2013). Since VSL does not account for loss of quality of life due to injury, medical expenses associated with non-fatal injuries involved in the observed motor vehicle accidents, or property damage, these extra costs are not included in the calculations. By excluding drunk pedestrians (which comprise a large fraction of all pedestrians killed in fatal accidents) we are not counting the external cost of those fatalities, either. Finally, the emotional and material losses of friends and family members are not included in the tallies.

For each combination of the number of vehicles and the number of drunk drivers involved in a crash we calculate the number of accidents and fatalities due to externalities. We also multiply by the fraction of drivers involved in an accident who were drunk since it is not possible to know which driver caused the accident. This yields the number of additional accidents and fatalities that occurred compared to the counterfactual. For example, relative to the counterfactual scenario where all drunk drivers were instead sober, in 2012 there were an additional 2,784 fatalities, or 9.0% more fatal accidents than there would have been otherwise. Implementing the VSL used in DOT policy recommendations starting in 2012 of $9.1 milion per life lost (DOT, 2013), this yields a total estimated external cost of drunk driving of approximately $25.34 billion in 2012.

The external cost per mile driven by drunk drivers requires the mean number of miles driven by drunk-drivers. Following LP, we calculate this as the product of the mean annual vehicle miles travelled over each five-year period in our sample; the percentage of miles driven between 8pm and 5am (16% according to results reported by Festin (1996) and employed by LP); and the estimated percentage of drunk drivers as reported in Figure 2. Our estimate of the external cost per vehicle mile traveled by legally drunk drivers are plotted in Figure 3. While far from monotonic, there is a clear trend of a decreasing external cost to drunk-driving.

VII. Conclusion

In this paper we trace the evolution of the relative risk of legally drunk and drinking drivers in causing a fatal accident using the universe of accidents in the U.S. involving a fatality over the past thirty years. We first document that while the relative risk of all drinking drivers to those who are non-drinking has remained relatively stable or even declined, that for legally drunk drivers has *increased by* approximately one-third to one-half.

We also demonstrated that there has been a steady decline in drunk-driving over time, suggesting that attempts to change the social acceptance of drunk-driving and/or better enforcement of drunk-driving laws has been successful.

In addition, we found that the external cost associated with drunk-driving has been trending downward. How is it possible that the relative risk of drunk-drivers has increased, but the external cost has decreased? While drunk drivers have been more risky relative to sober drivers, it is clear from the decline in total motor vehicle accident fatalities that advances in car safety technology have resulted in lower fatality risk overall. Although these advances have been sober-biased, they have nonetheless reduced the external cost that drunk drivers impose on society.

Our decomposition of fatal accident risk into the risk of causing a serious accident and the risk of dying in a serious accident reveals that the increase in the relative risk of drunk drivers over the past thirty years is driven entirely by an increase in the relative risk of causing a serious accident. Further, most of this increase in relative risk has emerged in the past decade. This does not necessarily imply that drunk drivers have become absolutely more risky. Given the large decline in fatal motor-vehicle accidents, it is possible that changes in automobile technology and the driving environment have decreased the risk of sober drivers more than it has decreased the risk of drunk drivers. Nevertheless, this suggests that further research into the differential effects of safety technology, road design, and other policies aimed at reducing fatal crashes overall may yield insights into how to refocus future policies on specifically reducing the risk of legally drunk and otherwise dangerous drivers.

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Table 1. Summary Statistics for Fatal Crashes in the Sample:
One-and Two-Car Crashes between 8:00 p.m. and 5:00 a.m.

Variable	1983-1993	1994-2003	2004-2012
Total number of one-car crashes	130501	101150	86362
Total number of two-car crashes	48047	34366	27463
Percentage of all drivers in fatal crashes:			
Who were drinking (BAC > 0.02)	65.92%	57.28%	56.39%
Male	82.56%	79.76%	78.98%
And reported to be drinking	56.06%	47.77%	46.58%
Under age 25	38.34%	33.20%	30.79%
And reported to be drinking	25.41%	18.49%	17.46%
Bad previous driving record	54.85%	50.59%	48.31%
And reported to be drinking	38.21%	31.23%	29.26%
Percentage of fatal one-car accidents with:			
One non-drinking driver (BAC <= 0.02)	23.34%	31.15%	31.70%
One drinking driver (BAC > 0.02)	76.66%	68.85%	68.30%
One sober driver (BAC <= 0.1)	44.72%	51.61%	52.96%
One legally drunk driver (BAC > 0.1)	55.28%	48.39%	47.04%
Percentage of fatal two-car accidents with:			
Two non-drinking drivers	19.41%	30.25%	32.09%
One drinking, one non-drinking driver	51.29%	49.90%	50.15%
Two drinking drivers	29.30%	19.85%	17.76%
Percentage of fatal two-car accidents with:			
Two sober drivers	44.10%	54.67%	57.79%
One legally drunk, one sober driver	48.40%	41.13%	38.92%
Two legally drunk drivers	7.49%	4.20%	3.29%

Note—Means are based on two-car crashes in FARS data between the hours of 8:00 p.m. and 5:00 a.m. Blood alcohol content (BAC) is the average BAC from the ten imputations that are provided in FARS and calculated according to NTHSA procedures. A bad driving record is defined as two or more minor blemishes (a moving violation or previous accident) or one or more major blemishes (previous DUI conviction, license suspension, or license revocation) in the last five years.

Table 2. Summary Statistics for Crashes with at least One Driver Death:
One-and Two-Car Crashes between 8:00 p.m. and 5:00 a.m.

Variable	1983-1993	1994-2003	2004-2011
Total number of two-car crashes with driver fatality	35856	25396	18729
Per year	3259.6	2539.6	2341.1
Percentage with two driver fatalities	6.0%	5.9%	5.1%
Percentage with one driver fatality	94.0%	94.1%	94.9%
Drunk driving			
Percentage with two driver fatalities and:			
Both drivers BAC<0.1	1.4%	2.0%	2.0%
One driver BAC>0.1, one driver BAC<0.1	3.4%	3.2%	2.7%
Both drivers BAC>0.1	1.2%	0.7%	0.5%
Percentage with one driver fatality and:			
Both drivers BAC<0.1	36.5%	47.1%	50.6%
Deceased driver BAC>0.1, surviving driver BAC<0.1	35.5%	31.3%	29.2%
Deceased driver BAC<0.1, surviving driver BAC>0.1	14.2%	11.3%	11.6%
Both drivers BAC>0.1	7.9%	4.3%	3.5%
Drinking and driving			
Percentage with two driver fatalities and:			
Both drivers BAC<0.02	0.6%	1.1%	1.2%
One driver BAC>0.02, one driver BAC<0.02	2.9%	3.0%	2.6%
Both drivers BAC>0.02	2.5%	1.8%	1.3%
Percentage with one driver fatality and:			
Both drivers BAC<0.02	16.2%	26.5%	28.7%
Deceased driver BAC>0.02, surviving driver BAC<0.02	33.8%	34.5%	33.8%
Deceased driver BAC<0.02, surviving driver BAC>0.02	15.5%	14.5%	15.8%
Both drivers BAC>0.02	28.6%	18.7%	16.6%

Note—Means are based on two-car crashes in FARS data between the hours of 8:00 p.m. and 5:00 a.m. in which at least one driver dies. Blood alcohol content (BAC) is the average BAC from the ten imputations that are provided in FARS and calculated according to NTHSA procedures.

Table 3. Likelihood of Causing a Fatal Crash Relative to Sober Drivers

		1983-1993	1994-2003	2004-2011
Drinking drivers	Relative risk of causing accident	3.436	2.488	3.240
		(0.147)	(0.160)	(0.198)
	Prob (death, drunk|death, drunk)	0.082	0.087	0.075
		(0.003)	(0.004)	(0.005)
	Prob (death, drunk|death, sober)	0.085	0.095	0.076
		(0.003)	(0.003)	(0.003)
	Prob (death, sober|death, drunk)	0.041	0.042	0.037
		(0.001)	(0.002)	(0.002)
	Prob (death, sober|death, sober)	0.038	0.039	0.040
		(0.002)	(0.002)	(0.003)
	Relative prob(death)	2.080	2.367	2.055
		(0.031)	(0.055)	(0.043)
Drunk	Relative risk of causing accident	6.130	6.423	8.177
		(0.224)	(0.328)	(0.498)
	Prob (death, drunk|death, drunk)	0.133	0.146	0.121
		(0.006)	(0.010)	(0.012)
	Prob (death, drunk|death, sober)	0.108	0.122	0.103
		(0.003)	(0.004)	(0.005)
	Prob (death, sober|death, drunk)	0.046	0.048	0.044
		(0.001)	(0.002)	(0.002)
	Prob (death, sober|death, sober)	0.037	0.041	0.037
		(0.002)	(0.002)	(0.002)
	Relative prob(death)	2.341	2.547	2.367
		(0.036)	(0.050)	(0.055)

Notes: Each entry is from a separate maximum likelihood estimation of equation X. A driver is classified as drinking if the average imputed BAC level is greater than 0.02. A driver is classified as drunk if the average imputed BAC level is greater than 0.10. The unit of observation is state x year x hour x weekend. Equal mixing is assumed at ***year x hour x weekend***. Standard errors in parentheses.

Table 4. Likelihood of Causing a Fatal Crash Relative to Sober Drivers

		I	II	III	IV	V	VI
Drinking drivers	Relative risk of causing accident	1.983	2.003	2.739	3.240	2.848	3.341
		(0.184)	(0.184)	(0.186)	(0.198)	(0.189)	(0.201)
	Relative prob(death)	2.055	2.055	2.055	2.055	2.055	2.055
		(0.043)	(0.043)	(0.043)	(0.043)	(0.043)	(0.043)
Drunk	Relative risk of causing accident	5.445	5.474	7.393	8.177	5.965	6.604
		(0.357)	(0.358)	(0.455)	(0.498)	(0.382)	(0.414)
	Relative prob(death)	2.367	2.367	2.367	2.367	2.367	2.367
		(0.055)	(0.055)	(0.055)	(0.055)	(0.055)	(0.055)
	Equal mixing:	All	Year	Year x Hour	Year x Hour x Weekend	State	State x Weekend

Notes: Each entry is from a separate maximum likelihood estimation of equation X. A driver is classified as drinking if the average imputed BAC level is greater than 0.02. A driver is classified as drunk if the average imputed BAC level is greater than 0.10. Standard errors in parentheses.

Figure 1: Likelihood of Causing a Fatal Crash Relative to Sober Drivers

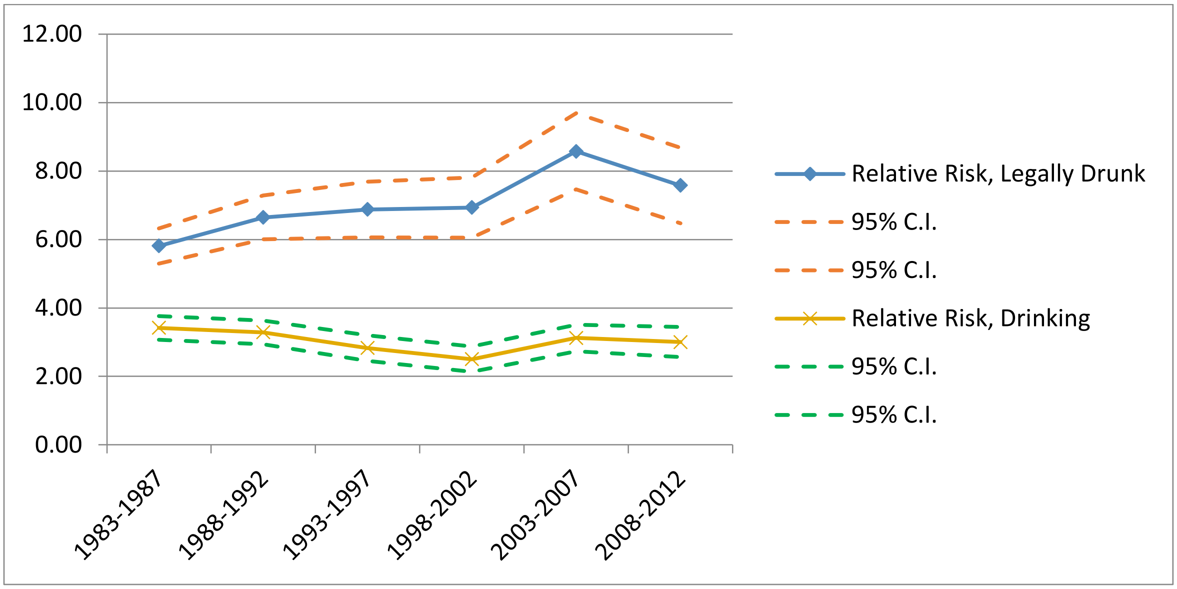


Figure 2: Proportion of Drunk-Drivers 8pm-5am

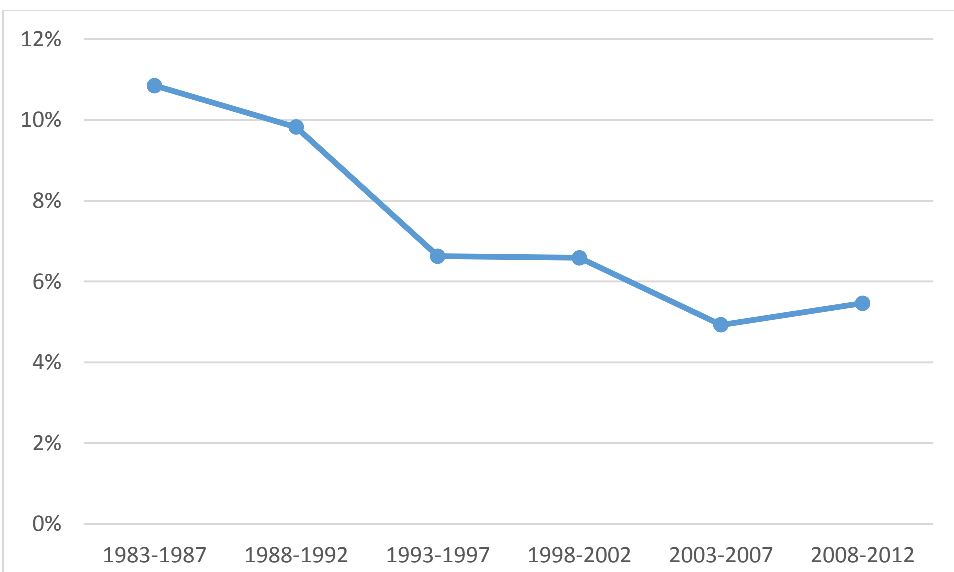
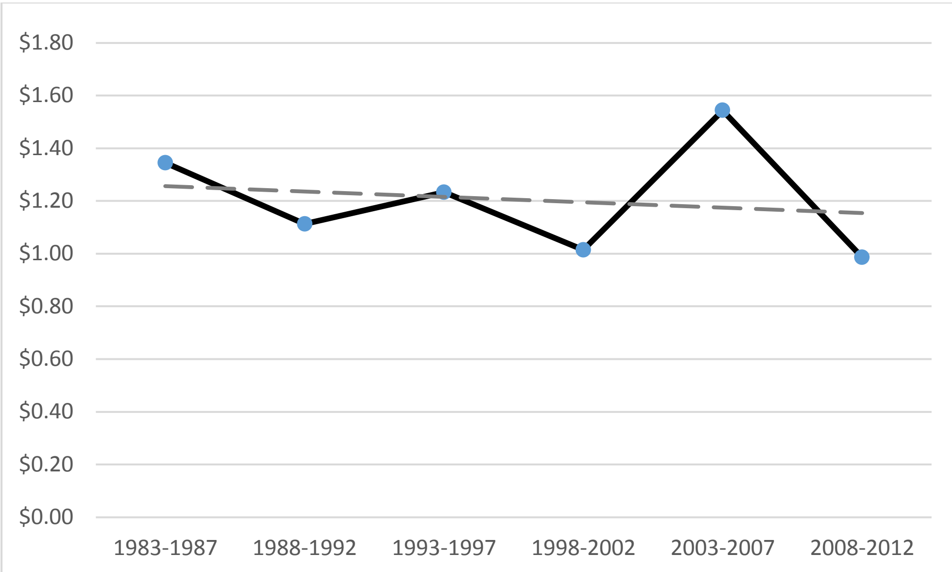


Figure 3: Externality to Drunk-Driving (per vehicle mile travelled)



Note: Dashed line is linear trend.