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Notes and comments

Exploring the relationship between vehicle safety and fuel efficiency in automotive design

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ABSTRACT

Panel data analysis is used within a fixed effect model to examine the relationship between vehicle safety ratings and fuel efficiency of 45 new vehicle models sold in the US between 2002 and 2007. While conventional wisdom and most early literature suggest that lighter, more fuel efficient vehicles are less safe to their occupants, the tests show a positive relationship between vehicle safety ratings and fuel efficiencies not only within and across most size classes but also for vehicles produced by both the US and Asian automakers. We also explore the design initiatives by manufacturers to compensate for the reductions in weight/size of fuel-efficient vehicles.

1. Introduction

The effect of fuel economy on automobile safety, which has been a controversial issue since the energy crises of the 1970s, now receives growing attention due to the significantly tougher Corporate Average Fuel Economy (CAFE) standards proposed by the US government. While the proponents of the new standards hail the potential benefits of energy and environmental conservation, the opponents argue that vehicle safety will be compromised with the tougher fuel economy standards. Studies done in the 1980s consistently report that higher fuel economy performances achieved by automakers through vehicle downsizing would significantly increase occupant fatality risk (Evans and Wasielewski, 1987). However, some recent studies show that the correlation between fleet fuel economy improvement and traffic fatalities is not necessarily positive (Ahmad and Greene, 2005; Noland, 2004, 2005). Suggested reasons for the weakening relationship between vehicle safety and fuel efficiency include drivers of light-weight vehicles off-setting the possibility of serious injury by less aggressive driving (Yun, 2002) and changes in the characteristics of other vehicles embracing stiffness and heights of the underlying structure (Toy and Hammitt, 2003).

We study the effect of automakers' multi-attribute design decisions on the relationship between vehicle safety and fuel efficiency based on the data of new vehicle models sold in the US using safety rating data published by the US National Highway Traffic Safety Administration (NHTSA), 2002–2007 and fuel efficiency data from the US Environmental Protection Agency (EPA) covering, 2002–2007. Since the focus is on automakers' design decisions, we use the safety rating data as a direct indicator of a vehicle's safety performance (Zachariadis, 2008). The time period allows us to compare possible changes in the relationship between vehicle safety and fuel efficiency with those before 2002 when most prior analysis was completed.

2. Data and methodology

The safety rating data is based on the crash test results of the New Car Assessment Program (NCAP) conducted by NHTSA. They comprise the government's 5-star results used to assist consumers in making purchasing decisions. Each year the

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Table 1
List of vehicle models.

Makers	Vehicle models	Size classes
Audi	A4	Compact car
Ford	Focus	Compact car
Honda	Civic	Compact car
Kia	Rio	Compact car
Mitsubishi	Lancer	Compact car
Toyota	Corolla	Compact car
Volkswagen	Jetta	Compact car
Volvo	S60	Compact car
Acura	TL	Mid-size car
Chevrolet	Malibu	Mid-size car
Chevrolet	Monte Carlo	Mid-size car
Chrysler	Sebring	Mid-size car
Honda	Accord	Mid-size car
Hyundai	Elantra	Mid-size car
Mitsubishi	Galant	Mid-size car
Nissan	Altima	Mid-size car
Nissan	Maxima	Mid-size car
Pontiac	Grand Prix	Mid-size car
Toyota	Camry	Mid-size car
Toyota	Prius	Mid-size car
Chevrolet	Impala	Large car
Ford	Crown Victoria	Large car
Ford	Taurus	Large car
Hyundai	Sonata	Large car
Lincoln	Town car	Large car
Mercury	Grand Marquis	Large car
Toyota	Avalon	Large car
Acura	MDX	Sport utility vehicle
Chevrolet	Trailblazer	Sport utility vehicle
Chrysler	PT cruiser	Sport utility vehicle
Ford	Explorer	Sport utility vehicle
GMC	Envoy	Sport utility vehicle
Honda	CR-V	Sport utility vehicle
Jeep	Grand Cherokee	Sport utility vehicle
Jeep	Liberty/Cherokee	Sport utility vehicle
Mercury	Mountaineer	Sport utility vehicle
Nissan	Frontier	Sport utility vehicle
Subaru	Forester	Sport utility vehicle
Suzuki	Grand Vitara	Sport utility vehicle
Toyota	Highlander	Sport utility vehicle
Toyota	RAV4	Sport utility vehicle
Chrysler	Town and country	Minivan
Dodge	Caravan	Minivan
Honda	Odyssey	Minivan
Kia	Sedona	Minivan
Toyota	Sienna	Minivan

agency chooses those new vehicles that are predicts to have high sale volume, those that have been redesigned with structural changes, and those with improved safety equipment to perform three different types of crash tests: frontal, side impact, and rollover tests. The frontal crash test (the equivalent of a single-car crash or a two-car crash between vehicles of similar size/weight) can only be compared with vehicles in the same class and within a 250 lbs weight range. The side impact test results can be compared with all vehicles, but since NHTSA did not start rollover tests until 2001, the data do not cover the entire analysis period. Therefore, the analysis focuses on the frontal and side impact tests only.[1]

The fuel efficiency data is based on the National Vehicle and Fuel Emissions Laboratory tests performed by EPA, with efficiency measured in miles per gallon weighted as an average of a 55% city and 45% highway driving cycle. Since NHTSA only conducts crash tests on selected models every years, initially the models with consistent frontal and side impact tests data for 2002–2007 are isolated, and their safety rating data are matched with their fuel efficiency data. Any model with missing safety rating data, as well as any model that was introduced after 2002 or discontinued before 2007 is excluded in the analysis. Additionally, since NHTSA does not specify the exact specification of each model subjected to safety tests, for those with multiple options, the average fuel efficiency of all the different options of the same model is used in the calculations. As a result, 45 models are identified with consistent safety rating and fuel efficiency data, embracing eight compact, 11 mid-size,

[1] Each frontal or side impact safety rating is based on the average of the frontal driver and passenger ratings or the side driver and passenger ratings for a vehicle model.

Table 2
Frontal, side impact, and average test results (all vehicle models).

All vehicles (270 observations)	Coefficient
Frontal safety rating vs. fuel efficiency	0.149**
Side impact safety rating vs. fuel efficiency	0.192**
Frontal safety rating vs. fuel efficiency	0.170**

* Denote statistical significance at 5% level.
** Denote statistical significance at 1% level.

and seven large cars, together with five minivans, and 14 SUVs (Table 1). By geographic region of automakers, 20 of the models were produced by US manufacturers, 22 by Asian, and three by European manufacturers.[2]

To establish a relationship, a panel data analysis is used with the fixed effect model (Wooldridge, 2001):

$$y_{it} = \beta x_{it} + v_i + \varepsilon_{it}, \tag{1}$$

where y_{it} and x_{it} are the safety rating and fuel efficiency of vehicle model i in year t, and v_i is any time-constant unobserved variable that affects the design of vehicle model i. β and ε_{it} are the regression coefficient and error term.[3] Averaging the equation over time for each vehicle model i leads to

$$\bar{y}_i = \beta \bar{x}_i + v_i + \bar{\varepsilon}_i. \tag{2}$$

Subtracting (2) from (1) for each year t, we have

$$y_{it} - \bar{y}_i = \beta(x_{it} - \bar{x}_i) + \varepsilon_{it} - \bar{\varepsilon}_i. \tag{3}$$

Parameters are estimated by pooled ordinary least squares. Since the time-constant variable has disappeared in the equation, there is no need to assume that v_i is uncorrelated with the independent variable as in standard regression estimation. We therefore focus on the time-dependent effect between vehicle safety and fuel efficiency (under short-term equilibrium conditions) while eliminating the effects of other factors which are known to influence both vehicle safety and fuel efficiency, such as mass and size.[4]

3. Results

Table 2 presents the test result for the 45 models based on the frontal, side impact, and average safety ratings (calculated by averaging the two individual ratings). The test results all show a significant positive relationship between vehicle safety ratings and fuel efficiencies. Since frontal safety ratings can only be compared to other vehicles in the same size class, the positive relationship between them and fuel efficiency is only applicable to cases involving single-car crashes or two-car crashes between vehicles of similar weights/sizes.[5] However, the test results based on the side crash ratings, which can be compared across all size classes, indicate that there exists a positive relationship between vehicle safety ratings and fuel efficiencies over the period.

We also group all the vehicle models by size class, that not only allows us to examine the relationship within classes, but also helps alleviate potential problems associated with the results of frontal tests only be comparable within the same class.[6] Table 3 presents the test results for compact cars, mid-size cars, large cars, SUVs, and minivans. The significant positive relationship between vehicle safety ratings and fuel efficiencies remains within most of the size classes except for result based on the frontal tests for compact cars and all the test results for minivans. While some of these statistically insignificant results may be due to limited variation in the data and small sample sizes, the positive relationships between safety ratings and fuel efficiencies observed in other classes support the findings based on all the vehicle models.

To see if the origin of vehicles is relevant, vehicles produced by US and Asian manufacturers are examined separately (Table 4). (European manufacturers are not included because of the small sample size.) The results based on the frontal, side impact, and average safety ratings again show significantly positive relationships between safety ratings and fuel efficiencies for vehicle models produced by both groups of automakers. The positive coefficients of the three safety ratings of US vehicles are all higher than those of Asian vehicles suggesting more effort spent by US automakers in improving simultaneously vehicle safety and fuel efficiency than their Asian counterparts.

[2] We only focus on vehicles powered by the conventional internal combustion engines, and exclude hybrid electric vehicles (HEVs) and vehicles powered by non-gasoline fuels.
[3] The random effect model is not used due to the possible correlation between fuel efficiency and mass or size, i.e., $Cov(x_{it}, v_i) \neq 0$.
[4] Since we use the fixed effect model to analyze the data, any time-invariant effects are eliminated. The estimation is thus conducted without a constant (Hsiao, 2003).
[5] According to the 2007 Traffic Safety Facts published by NHTSA (available at http://www.nhtsa.gov), occupant fatalities in single-car crashes accounted for 45% of all motor vehicle fatalities in 2007 while occupant fatalities in multiple-car crashes accounted for 42% of all fatalities, and the remaining 13% were non-occupant fatalities.
[6] The test results based on the frontal safety ratings should still be used with caution because the differences in weight between some of the vehicle models within the same class exceed the 250-pound limit for comparison specified by NHTSA.

Table 3
Frontal, side impact, and average test results by size classes.

Size class: subcompact/compact (48 observations)	Coefficient
Frontal safety rating vs. fuel efficiency	0.016
Side impact safety rating vs. fuel efficiency	0.190**
Frontal safety rating vs. fuel efficiency	0.103*
Size class: mid-size (66 observations)	Coefficient
Frontal safety rating vs. fuel efficiency	0.227**
Side impact safety rating vs. fuel efficiency	0.242**
Frontal safety rating vs. fuel efficiency	0.234**
Size class: large cars (42 observations)	Coefficient
Frontal safety rating vs. fuel efficiency	0.396**
Side impact safety rating vs. fuel efficiency	0.424**
Frontal safety rating vs. fuel efficiency	0.410**
Size class: SUVs/pickup trucks (84 observations)	Coefficient
Frontal safety rating vs. fuel efficiency	0.419**
Side impact safety rating vs. fuel efficiency	0.101**
Frontal safety rating vs. fuel efficiency	0.260**
Size class: minivans (30 observations)	Coefficient
Frontal safety rating vs. fuel efficiency	0.002
Side impact safety rating vs. fuel efficiency	0.024
Frontal safety rating vs. fuel efficiency	0.013

* Denote statistical significance at 5% level.
** Denote statistical significance at 1% level.

Table 4
Frontal, side impact, and average test results for US and Asian manufacturers.

US vehicles (120 observations)	Coefficient
Frontal safety rating vs. fuel efficiency	0.244**
Side impact safety rating vs. fuel efficiency	0.229**
Frontal safety rating vs. fuel efficiency	0.236**
Asian vehicles (132 observations)	Coefficient
Frontal safety rating vs. fuel efficiency	0.166**
Side impact safety rating vs. fuel efficiency	0.181**
Frontal safety rating vs. fuel efficiency	0.174**

* Denote statistical significance at 5% level.
** Denote statistical significance at 1% level.

4. Concluding remarks

While earlier analysis often suggests lighter, more fuel-efficient vehicles are less safe for their occupants, the relationships between vehicle safety ratings and fuel efficiencies seem to have been mostly positive from 2002 to 2007. This is in line with some of more recent reports based on pre-2002 data, which show either a positive relationship (Ahmad and Greene, 2005) or no relationship between vehicle fuel efficiency and traffic fatalities (Ross and Wenzel, 2002; Noland, 2004, 2005). Although the results based on frontal ratings cannot be directly extended to those cases of multiple-car crashes that involve vehicles of significantly different weights/sizes, they do show that fuel-efficient vehicles can also be as safe as, if not safer than, their low gas-mileage counterparts in accidents involving single-car crashes and side impact collisions.

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