The Effect of Fuel Economy Standards on Vehicle Weight Dispersion and Accident Fatalities

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Fuel Economy Standards

Fuel economy standards are a dominant policy to regulate light duty vehicle emissions worldwide.

- CAFE (Corporate Average Fuel Economy) standards in the U.S.
- CAFE standards require each automaker to meet a sales-weighted average fuel economy for each fleet–or pay a fine.
- They are widely considered a second-best policy to internalize air pollution and national security externalities.
    - Previous work suggests that direct compliance costs are not cheap: Jacobsen (2013), Anderson and Sallee (2011).

Yet CAFE is Set to be Tightened Further

On July 29, 2011 former President Obama announced an agreement to increase the industry-wide combined average fuel economy to 54.5 miles per gallon by model year 2025.

- This represents a dramatic increase from 27.3 miles per gallon for model year 2011.
- The January release of the EPA/NHTSA Midterm Review confirms this decision to ramp up standards despite lower gasoline prices.

It remains to be seen what the Trump Administration will do.

A Major Argument Against CAFE: Increased Fatalities

Crandall and Graham (1989) find CAFE lowered mean weight by 470 lbs.

- They noted that vehicles 500 lbs below the mean have higher fatalities (Evans 1984).

This is a big deal: Under standard VSL estimates, accident costs can quickly overshadow direct costs; it would only take less than 70 extra deaths annually.

Popular Conception: CAFE Kills

- "Depending on which study you choose, the total [number of deaths] ranges from 41,600 to 124,800." "In the past thirty years, fuel standards have become one of the major causes of death and misery in the United States" - Deroy Murdock, National Review.
- Attempt to increase in 1991 was opposed because it would "have adverse effects on vehicle safety" - Senator Richard Bryan (D-Nev).

The National Academy of Sciences (2002) report on CAFE even had a rare "dissenting opinion" on this hotly-debated issue.

Recent Studies Focus on Dispersion

"Arms Race" literature on link between weight and safety: White (2004), Gayer (2004), Anderson (2008), Li (2012), Anderson & Auffhammer (2013).

- Suggestive evidence that lowering weight of all vehicles reduces fatality risk.
- Fatality risk increases with increasing weight **dispersion**.
- Downweighting of lighter versus heavier vehicles leads to different fatality outcomes.

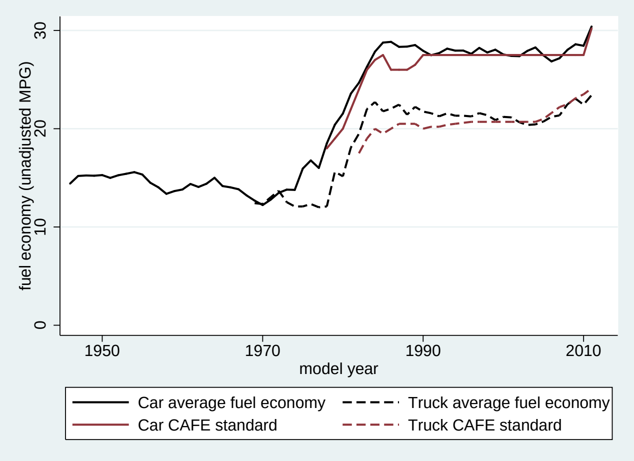
Existing literature does not fully trace out how CAFE changes total fatalities.

This Paper

Asks the following research questions:

1. How did automakers actually respond to CAFE?
    - We estimate the impact of fuel economy standards on the distribution of weight in the fleet.
2. How do changes in the fleet translate into accident fatalities?
    - We estimate fatality risk using state-level accident data.
    - We create a counterfactual weight distribution.
    - We simulate total changes in accident fatalities.
3. What does this imply for the net benefits of CAFE?

Empirical Setting



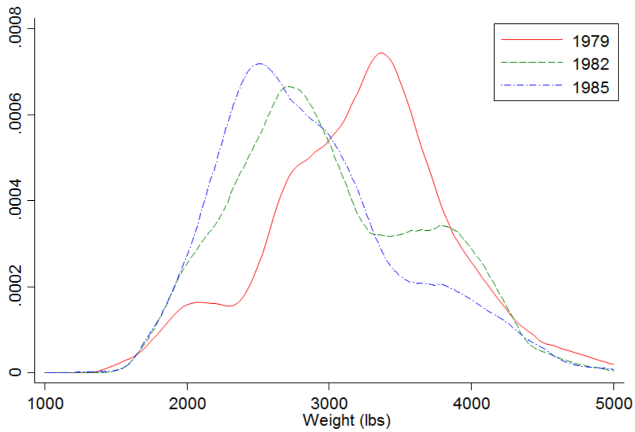
Now standard is "footprint"-based.

Potential Channels of Adjustment

Automakers can respond to the standards in several ways:

1. In the short-run, they can change relative prices of produced vehicles.
    - This is the only channel of adjustment in much previous structural work (Jacobsen 2012, Austin & Dinan 2005, Goldberg 1995, Bento et al. 2009, Gillingham 2012).
    - Klier and Linn (2013) suggest this is a more expensive approach.
2. In the medium/long-run, they can change product attributes.
    - Directly add new costly technology to improve fuel economy.
    - Shift along the production possibilities frontier (Whitefoot et al. 2013, Klier and Linn 2013, Roth 2013, Knittel 2011).
    - Comply using loopholes in CAFE (Anderson and Sallee 2011)

Preview: Shift in the Domestic Fleet



Estimation Approach: RIF Regressions

For each automaker-fleet, model the τ-quantile of vehicle weight, wt, as suggested in Firpo et al. (2009):

$$E[RIF(wt_{f,i,t}; q_\tau)|S_{f,t-1}, Z_{f,i,t-1}] = \beta_\tau S_{f,t-1} + Z'_{f,i,t-1}\gamma_\tau + \zeta_f.$$

- RIF is a transformation of each observation of wt.
- q_τ is the τ-quantile (or other statistic: variance, Gini).
- S_{jt} is stringency of regulation on fleet f in time $t-1$.
- X_{tj} is a vector of controls (lag gasoline prices, lag GDP, lag fleet weight, quadratic time trend).
- ζ_f are automaker-fleet fixed effects.

Interpretation: β_τ is the effect of S on the τ-th **unconditional** quantile of wt (just as OLS gives the effect on the mean).

Measuring the Stringency of CAFE

Measuring the stringency of CAFE standards is tricky. Three options:

- **Difference between standard and "predicted CAFE"**.
  - $S_{f,t-1} = ln(CAFE_{t-1}) - ln(\widehat{MPG_{f,t-1}})$
  - Calculate predicted firm-specific fuel economy based on pre-CAFE period.
  - Captures real sources of variation that can be used.
- Level of the CAFE standards.
  - Does not easily permit counterfactuals.
- CAFE credit balances.
  - Based on banking and borrowing decisions; can be hard to interpret.

We find similar results using all three approaches

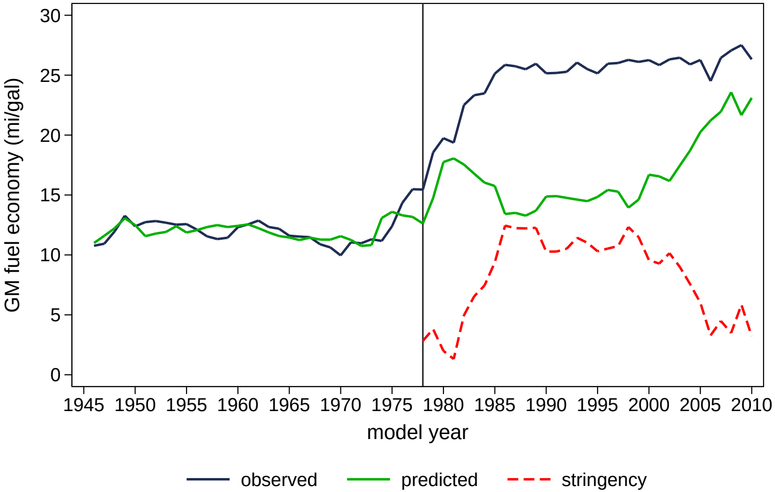
Counterfactual Fuel Economy

Inspired by a measure used in Small & Van Dender (2007)

- Use coefficients from pre-1978 regression of mpg on gasoline price, GDP, and a quadratic time trend (by automaker-fleet at trim-level).
- Central specification: average across $t-3$, $t-2$, $t-1$, t, and $t+1$.
- Key caveat: Are coefficients from the 1960s applicable to 2010?

Counterfactual Fuel Economy

To see the variation underlying our results:



Data

Our primary data sources:

- Wards Automotive Yearbook 1971-2011.
  - make, model, trim, model year, weight, horsepower, RPM, diesel, fuel economy, sales (at model-level).
  - 94,000 trims; 10,000 models; 18 classes.
- Automobile-catalog.com 1948-2011.
  - make, model, trim, model year, weight, horsepower, RPM, diesel, fuel economy.
  - Data for most, but not all, makes.
  - Unique in giving a detailed picture pre-CAFE standards.
- National retail gasoline prices (EIA).
- Gross domestic product (BEA).

Domestic Car Results

Panel A: Fuel Economy Regressions[a]

	I	II	III	IV	V	VI
Regressand	OLS	Q10	Q25	Q50	Q75	Q90
$\frac{\sum_{i=-1}^{3} S_{t-i}}{5}$	-0.299***	-0.536***	-0.553***	-0.304***	-0.222***	-0.214***
	(0.027)	(0.049)	(0.059)	(0.054)	(0.048)	(0.044)
$l(Gasoline\ Price_{t-1})$	-0.284***	-0.338***	-0.555***	-0.422***	-0.164***	-0.114***
	(0.014)	(0.023)	(0.026)	(0.028)	(0.027)	(0.024)
$l(GDP_{t-1})$	-0.292***	0.175	-0.209	-0.105	-0.441**	-0.438**
	(0.082)	(0.147)	(0.155)	(0.151)	(0.155)	(0.135)
Weight in Quantile[b]	3,023.4	2,280.0	2,582.0	3,001.0	3,429.0	3,803.0
Weight Change for 1MPG[b]	-32.8	-44.4	-51.9	-33.2	-27.7	-29.6
R-squared	0.132	0.064	0.109	0.126	0.073	0.048
N	15,021	15,021	15,021	15,021	15,021	15,021

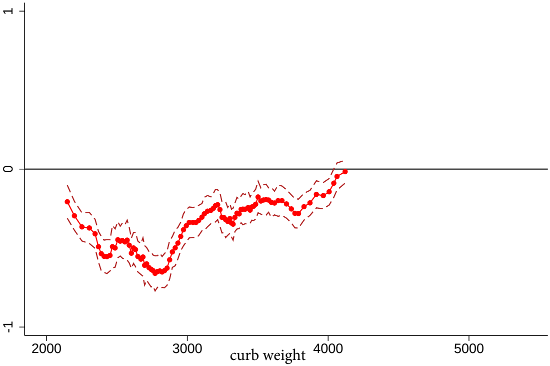
Notes: All regressions include a quadratic trend and automaker fixed effects. Bootstrap standard errors in parentheses with * indicating significance at 5%, ** at 1%, and *** at $>$1%.

[a] Predicted Fuel Economy Regressions use 1978 to 2005. To predict the fuel economy without CAFE for a given fleet (S_{t-i}) the harmonic mean fuel economy of the fleet produced prior to CAFE is regressed on a trend, the gasoline price, and GDP. These coefficients are then used to predict the fuel economy level after the introduction of the CAFE standard. This is done separately for each automaker and each fleet (cars vs. light trucks).

[b] Weight in pounds.

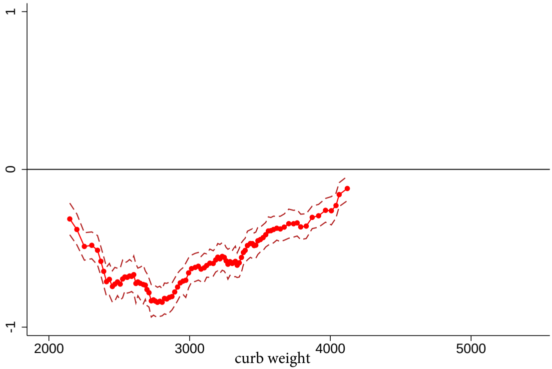
Graphical Results: Domestic Cars

Primary results using the average from $t-3$ to $t+1$



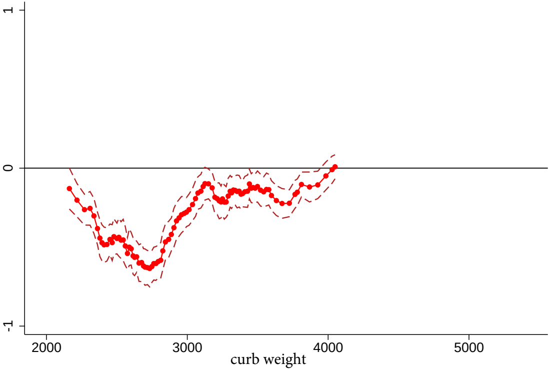
Robustness: Domestic Cars

Results using just $t-1$ for the stringency



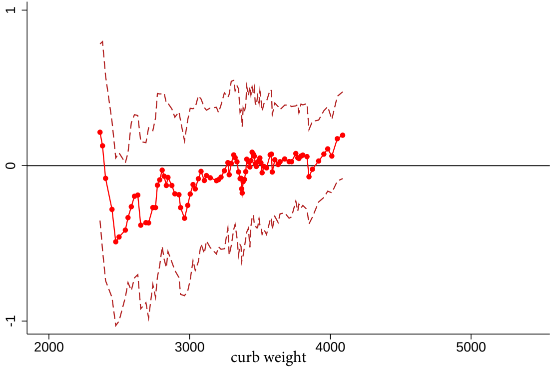
Robustness: Domestic Cars

Results using the CAFE level



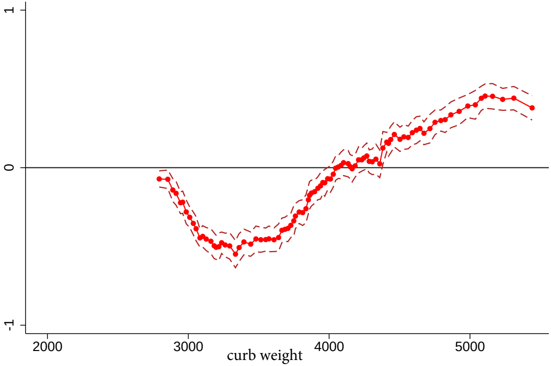
Robustness: Domestic Cars

Sales-weighted results (at the model-level)



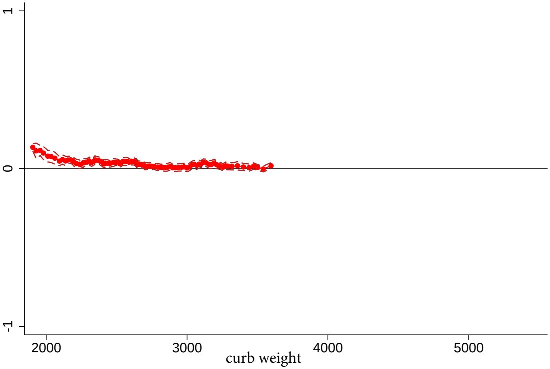
Results for Trucks

Using our primary specification



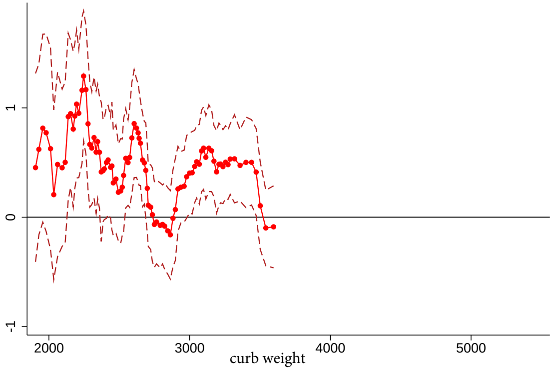
Competitive Effects: Asian Automakers

The effect of own stringency on weight



Competitive Effects: Asian Automakers

The effect of competitor's stringency on own weight



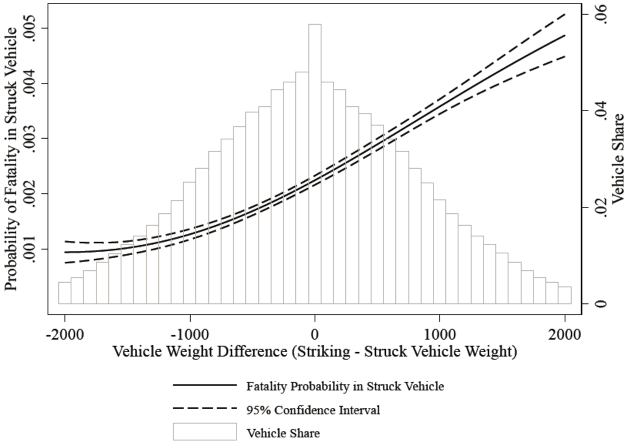
Summary of the Effect of CAFE on Weight

- Domestic Automakers:
  - Down-weight lighter vehicles.
  - $\Rightarrow$ Lower mean, higher dispersion.
- Asian Automakers:
  - No response to own stringency (CAFE not binding).
  - Upweight in response to domestic stringency.
  - This could offset some dispersion.

Weight and Fatalities

Anderson & Auffhammer (2013) estimate relationship between weight difference and fatalities

Figure 2: Relationship Between Difference in Vehicle Weights and Struck Vehicle Fatalities



Accident Data

NHTSA State Data System:

- Population of all police-reported accidents.
- Includes vehicle information and fatality counts.
- $\sim$30 million accidents from various states 1995-2009.
- We examine 1, 2, and 3-vehicle crashes.
    - We hold pedestrian, motorcycle, and heavy truck accidents fixed.
    - We have to drop vehicles that are not identifiable.
- Final sample of $\sim$17 million accidents.

Accident Summary Statistics

Counterfactual Simulation

Question: How do these effects map into accident injuries and fatalities?

1. Goal is to examine a counterfactual "world without CAFE."
2. A focus will be on the geographic heterogeneity of the fleet and changes over time.

Summary of Accident Results

We estimate the probability of a fatality as a function of weight and controls.

- Lower total weight $\Rightarrow$ lowers fatalities.
  - Consistent with Anderson and Auffhammer, although their result is not statistically significant.
  - Larger vehicles carry more kinetic energy, so vehicle must absorb more energy (Wenzel 2013).
- Weight dispersion $\Rightarrow$ increases fatalities.
  - Same result as in Anderson and Auffhammer.

One Vehicle Accident Results Two Vehicle Accident Results Three Vehicle Accident Results

Translate Results to Fatalities

Did CAFE standards kill?

- Pick the year 2005 to look at accidents in equilibrium.
- Change the distribution of weights in each prior year based on the RIF regressions.
- Set CAFE stringency equal to zero.
- This gives us a new counterfactual vehicle fleet.
- Recalculate the fatality rate in all 17 million crashes.
- Extend nationally.
  - Impute county level % change in fatalities based on county characteristics: population, fatalities, % domestic, % light truck, average vehicle weight, average vehicle age.

Fatality Results: National

Panel C: Impute to National Level, Remove CAFE for Domestic Firms[a]

	1-car	2-car	3-car	Total
Change Dispersion Only	0.0	-100.0	-10.5	-110.4
Change Mean Weight Only	342.7	155.3	51.6	549.7
Total Change	342.7	55.4	41.1	439.2

Panel D: Impute to National Level, Remove CAFE for All Firms[a]

	1-car	2-car	3-car	Total
Change Dispersion Only	0.0	395.4	87.4	482.8
Change Mean Weight Only	-20.7	-49.7	-19.3	-89.7
Total Change	-20.7	345.7	68.1	393.1

Notes: Calculates change in fatalities if CAFE is removed and the stringency is set to zero. Positive values indicate that CAFE saved lives in 2005.
[a] Because the states with SDS accident data tend to be Eastern and Midwest we impute a percent change in fatality rate based on county population, total fatalities, and state level average vehicle weight, age, share light truck, and share US and Asian manufacturer. This imputation tends to reduce lives saved because western counties have low population density and have a larger share Asian manufacturer.

Role of the Footprint

Current CAFE standards are footprint-based.

- Historically, weight and footprint were closely linked (elasticity of 0.7).
- With footprint-based standards, firms have an incentive to down-weight, but (weakly) increase the footprint.
- We find that ceteris paribus increasing the footprint reduces fatalities.
- So holding the footprint constant in our simulations would imply even more lives saved.

Discussion

- Benefits of our simulation approach:
  - Transparent methodology.
  - Preserves sorting of vehicles by city and driver type.
- Possible concerns:
  - Capturing the equilibrium, rather than transition.
  - CAFE would change total sales and driving (rebound effect).
  - Driver or firm responses to lighter vehicles? Peltzman effect? Safety equipment to riskier vehicles?
  - Different vehicles would be sold? Klier & Linn (2013) show this is an expensive compliance strategy.

Costs and Benefits of CAFE

- Projected compliance cost is $1.5 billion annually (EPA RIA).
  - Can add on $0.2 billion from additional externality costs.
  - Some work has suggested lower compliance costs (Anderson and Sallee 2011), while others have suggested higher costs (Jacobsen 2013).
- Using a VSL of $9.1 million, the benefits of reduced fatalities exceed $3.5 billion.
- Thus, CAFE has **positive net benefits** from reduced fatalities alone.
- Currently CAFE is justified based on myopic consumers not recognizing the benefits of future fuel savings.
  - Called into question: Busse et al. 2013, Allcott & Wozny 2014, Sallee et al. 2016.

Conclusions

- First study to directly measure the effect of CAFE on weight dispersion.
  - Use new approach (Firpo et al. 2009) from labor literature.
  - Find down-weighting of smaller domestic vehicles.
- We link this dispersion with firm compliance strategy, showing competitive effects of CAFE.
- Estimate the effect of mean weight and dispersion on accident fatalities.
- Show that CAFE likely **saved** several hundred lives.
- This alone could justify CAFE on net benefit grounds.
  - Footprint-based standards are unlikely to be optimal, but would only strengthen this result.

Thank you!

Comments and suggestions are welcome!

Appendix: Summary Statistics for Accident Data

Panel B: Vehicles Usable for Regressions

	Accidents			
State	With VINS	Vehicle Count 1, 2, or 3	VINs Decode with Weight	Fraction in Final Set
Florida	3,384,336	3,079,875	1,731,365	0.42
Georgia	3,542,542	3,444,921	2,006,915	0.51
Illinois	5,058,120	4,879,232	2,372,437	0.35
Kansas	622,055	604,028	339,330	0.28
Michigan	1,868,712	1,816,707	1,559,079	0.72
Missouri	2,424,946	2,347,948	1,231,635	0.42
Nebraska	486,593	472,309	292,833	0.52
New Mexico	885,347	845,674	448,372	0.36
New York	2,687,175	2,471,994	2,268,631	0.66
North Carolina	2,685,769	2,543,650	2,006,645	0.68
Pennsylvania	2,841,573	2,689,781	1,835,255	0.60
Virginia	270,582	256,858	124,767	0.27
Washington	1,053,755	1,001,976	823,970	0.61
Total	27,811,505	26,454,953	17,041,234	0.57

Back

Appendix: One Vehicle Accidents

Table: Accident Regressions

Panel A: One Vehicle Crashes	I	II	III	IV	V
Weight (1000 lbs)	-0.00015***	0.00126***	0.00201***	0.00200***	0.00249***
	(0.00006)	(0.00012)	(0.00012)	(0.00012)	(0.00030)
Pickup Truck	0.00196***	0.00296***	0.00259***	0.00260***	0.00199***
	(0.00015)	(0.00019)	(0.00018)	(0.00018)	(0.00036)
Van or SUV	0.00086***	-0.00011	-0.00040***	-0.00039***	0.00084**
	(0.00014)	(0.00013)	(0.00013)	(0.00013)	(0.00033)
Footprint		-0.00005***	-0.00005***	-0.00005***	-0.00004***
		(0.00000)	(0.00000)	(0.00000)	(0.00001)
Model Year			-0.00024***	-0.00026***	-0.00006**
			(0.00001)	(0.00001)	(0.00002)
Trend				0.00006**	-0.00036***
				(0.00002)	(0.00005)
County fixed effects	Y	Y	Y	Y	Y
Controls for Speed and Seatbelts	N	N	N	N	Y
N	7,345,248	7,345,248	7,345,202	7,345,202	1,639,271

Notes: Standard errors in parentheses clustered at the county level with * indicating significance at 5%, ** at 1%, and *** at >1%.

[a] Dummies for all combinations of Car, Van/SUV, and Pickup Truck. Two car or three car accidents omitted.

Back

Appendix: Two Vehicle Accidents

Table: Accident Regressions

Panel B: Two Vehicle Crashes	I	II	III	IV	V
Abs(Weight Difference) (in 1000s)	0.00068***	0.00057***	0.00056***	0.00056***	0.00059***
	(0.00005)	(0.00005)	(0.00005)	(0.00005)	(0.00011)
Sum of Vehicle Weights	0.00003	-0.00002	0.00021***	0.00021***	0.00038***
	(0.00003)	(0.00004)	(0.00004)	(0.00004)	(0.00011)
	(0.00010)	(0.00011)	(0.00011)	(0.00011)	(0.00026)
Footprint of Smallest Vehicle		-0.00000**	-0.00001***	-0.00001***	-0.00001*
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
Footprint of Largest Vehicle		0.00001***	0.00000**	0.00000**	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
Oldest Model Year			-0.00005***	-0.00005***	0.00002
			(0.00001)	(0.00001)	(0.00001)
Youngest Model Year			-0.00005***	-0.00005***	-0.00001
			(0.00001)	(0.00001)	(0.00001)
Trend				0.00001	-0.00015***
				(0.00001)	(0.00003)
County fixed effects	Y	Y	Y	Y	Y
Class Dummies[a]	Y	Y	Y	Y	Y
Controls for Speed and Seat belts	N	N	N	N	Y
N	8,956,966	8,956,966	8,956,966	8,956,966	2,125,543

Notes: Standard errors in parentheses clustered at the county level with * indicating significance at 5%, ** at 1%, and *** at >1%.

[a] Dummies for all combinations of Car, Van/SUV, and Pickup Truck. Two car or three car accidents omitted.

Back

Appendix: Three Vehicle Accidents

Table: Accident Regressions

Panel C: Three Vehicle Crashes	I	II	III	IV	V
Std. Dev. of Weights	0.00191***	0.00133***	0.00128***	0.00128***	0.00192**
	(0.00029)	(0.00034)	(0.00034)	(0.00034)	(0.00078)
Sum of Weights	0.00025***	0.00023**	0.00049***	0.00049***	0.00058**
	(0.00009)	(0.00012)	(0.00013)	(0.00012)	(0.00028)
Footprint of Smallest Vehicle		-0.00002**	-0.00002**	-0.00002**	-0.00001
		(0.00001)	(0.00001)	(0.00001)	(0.00002)
Footprint of Largest Vehicle		0.00001***	0.00001**	0.00001**	-0.00001
		(0.00000)	(0.00000)	(0.00000)	(0.00001)
Oldest Model Year			-0.00012***	-0.00012***	-0.00008
			(0.00002)	(0.00002)	(0.00005)
Youngest Model Year			-0.00003	-0.00003	0.00002
			(0.00003)	(0.00003)	(0.00009)
Trend				-0.00001	-0.00022**
				(0.00004)	(0.00009)
County fixed effects	Y	Y	Y	Y	Y
Class Dummies[a]	Y	Y	Y	Y	Y
Controls for Speed and Seatbelts	N	N	N	N	Y
N	739,020	739,020	739,020	739,020	190,249

Notes: Standard errors in parentheses clustered at the county level with * indicating significance at 5%, ** at 1%, and *** at $>$1%.

[a] Dummies for all combinations of Car, Van/SUV, and Pickup Truck. Two car or three car accidents omitted.

Back