Relationships between Vehicle Mass, Footprint, and Societal Risk

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Overview

Timeline

- Start date: Mar 2010
- End date: Sep 2013
- 80% complete

Budget

- Total funding: $992,000
- FY12: $275,000
- FY13: $248,000

Barriers

- Barriers addressed
  - Fuel economy not top criterion when purchasing vehicle
  - Mass reduction is a cost-effective approach to improve fuel economy
  - Concern that mass reduction may reduce societal safety

Partners

- DOT National Highway Traffic Safety Administration
- EPA Office of Transportation and Air Quality

Relevance

- Objective: Estimate how changes in weight and size of contemporary vehicles would have affected historical societal risk, holding footprint and other variables constant
- Results will enable NHTSA and EPA to set appropriate new vehicle standards that will encourage down-weighting of vehicles without affecting safety
- These standards will in turn encourage manufacturers to use advanced lightweight materials to reduce new vehicle weight without necessarily reducing size
- Standards will overcome some of the reluctance of consumers to purchase vehicles with high fuel economy

Strategy

- Facilitate collaboration among DOE, NHTSA and EPA
- Improve upon, and increase transparency of, previous NHTSA analyses
- Phase 1: Replicate NHTSA 2012 regression analysis of US societal fatality risk per vehicle mile traveled (VMT)
  - Advise NHTSA on data, variables, and methods
- Phase 2: Conduct separate regression analysis of casualty (fatality + serious injury) risk using data from 13 states
  - Provide another perspective from NHTSA analysis
- Results used in DOT Volpe model to forecast effect of MY2017 to 2025 fuel economy/CO_2 emission standards on fatalities and casualties: 2012 Final Rule and upcoming Mid-term Review
- Databases and programs made public, to allow replication of results

Two Analytical Approaches

- NHTSA analyses (1997, 2003, 2010, 2012)
  - Numerator: US fatalities, from FARS
  - Denominator: vehicle miles traveled (VMT)
    - Uses detailed information on drivers and crashes from police-reported crashes in 13 states
    - Applies a weight to each vehicle in state crash data to scale up to national vehicle registrations (RL Polk)
    - Applies average annual miles driven by make/model (RL Polk)
  - Result: US fatalities per vehicle miles traveled (VMT)
- LBNL analysis (2010, 2012)
  - All data from police-reported crashes in 13 states
  - Numerator: fatalities or casualties (fatalities + serious injuries)
  - Denominator: all crash-involved vehicles
  - Result: 13-state fatalities or casualties per crash
  - Also two components of casualties per VMT:
    - Crash frequency: crashes per mile traveled, using NHTSA weights
    - Crashworthiness/compatibility: casualties per crash

Similarities in Two Approaches

- Both use multiple logistic regression to estimate effect of reducing vehicle mass on societal risk, while holding footprint constant
  - Model estimates likelihood that a specific crash resulted in fatality or casualty, to occupants in case vehicle and any crash partner (societal risk)
  - Three vehicle types (cars, light trucks, crossover utility vehicles/minivans); car and truck types each split into lighter- and heavier-than-average
  - Nine crash types
  - 3 x 9 = 27 regression models; results are weighted by effectiveness of ESC in 2017 (assumed large reductions in rollovers and 1-vehicle crashes with objects)
  - ~ 28 variables control for other vehicle (side airbags, ESC, etc.), driver (age and gender), and crash (urban/rural, night, high-speed roads, etc.) characteristics
- Both use same database of vehicle characteristics
  - Make/model, body type, curb weight, footprint, airbags, ABS, ESC, etc.
- Both estimate the recent <u>historical</u> relationship between vehicle mass or size and societal risk
- Neither can predict this relationship in the <u>future</u>, with new lightweight materials and vehicle redesign

Differences in Two Approaches

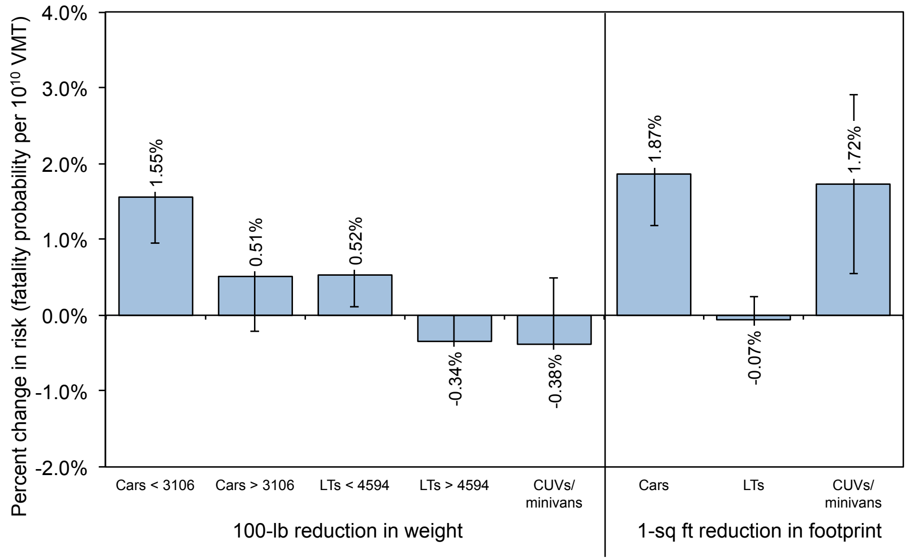
- Benefits of LBNL approach
  - All data from same source (13 states crash data)
  - Estimates relationship of mass/size reduction on serious injuries <u>and</u> fatalities
  - Allows analysis of two components of casualty fatalities per VMT
    - Crash frequency (crashes per VMT)
    - Crashworthiness/compatibility (risk once a crash has occurred)
- Drawbacks of LBNL approach
  - Limited to 13 states that provide Vehicle Identification Number (VIN)
    - Does relationship between weight/size and risk vary by state?
    - Are 13 states representative of national relationship?
  - Not enough fatalities in 13 states to also get robust results for fatality risk

Technical Accomplishments and Progress

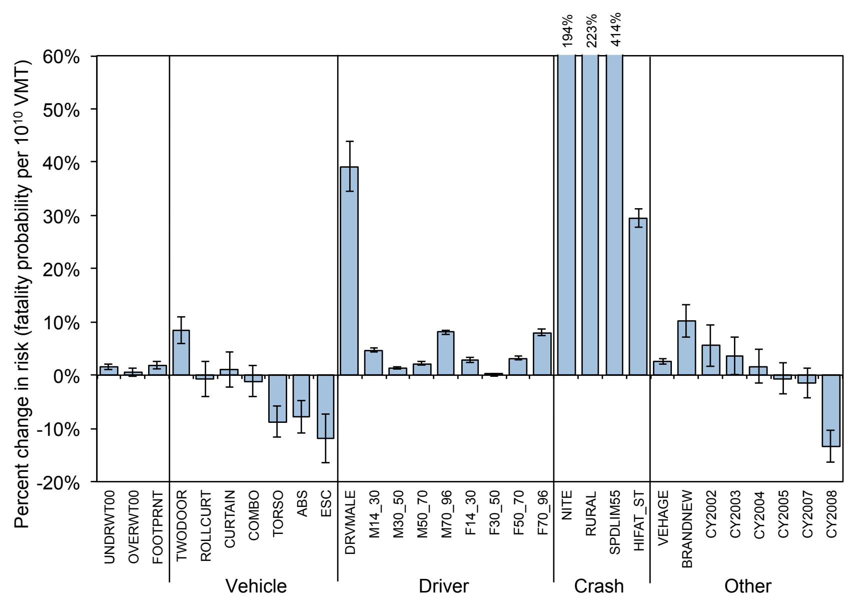
- Phase 1: replicated NHTSA analysis of US fatality risk per VMT (preliminary Sep 2011; final Aug 2012)
- Phase 2: estimated 13-state casualty risk per crash (preliminary Nov 2011; final Aug 2012)
- Contributed to sections on safety in EPA/NHTSA NPRM (Nov 2011) and Final Rule (Jul 2012)
- Responded to comments in formal peer review (funded by EPA; Aug 2012)
- Submitted three journal articles to *Accident Analysis and Prevention*
- Reviewed DRI 2012 report, and repeated two-stage regression model (draft Jan 2013)
  - Dynamic Research Inc., funded by International Council for Clean Transportation
  - Model simultaneously estimates crash frequency and crashworthiness components of US fatality risk per VMT

Conclusions from Phase 1

- Estimated effect of mass or footprint reduction on societal risk is small
  - Mass reduction associated with a statistically-significant increase in risk only for lighter-than-average cars (1.55%)
  - Footprint reduction associated with increases in risk in cars and CUVs/minivans
  - Mass effects smaller than in previous NHTSA studies

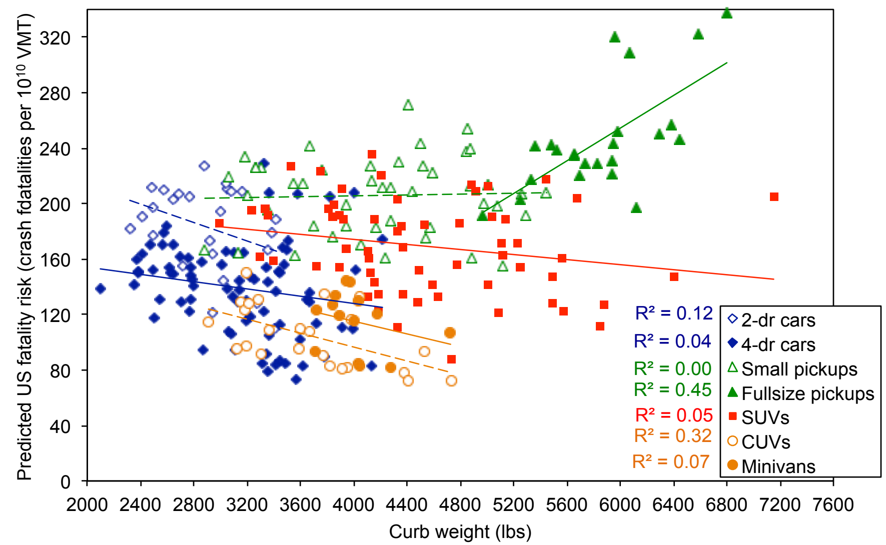


- Effect of mass or footprint reduction is overwhelmed by other factors (results for cars shown)
  - Other vehicle characteristics nearly 10x larger
  - Driver gender up to 25x larger
  - Certain crash characteristics over 200x larger

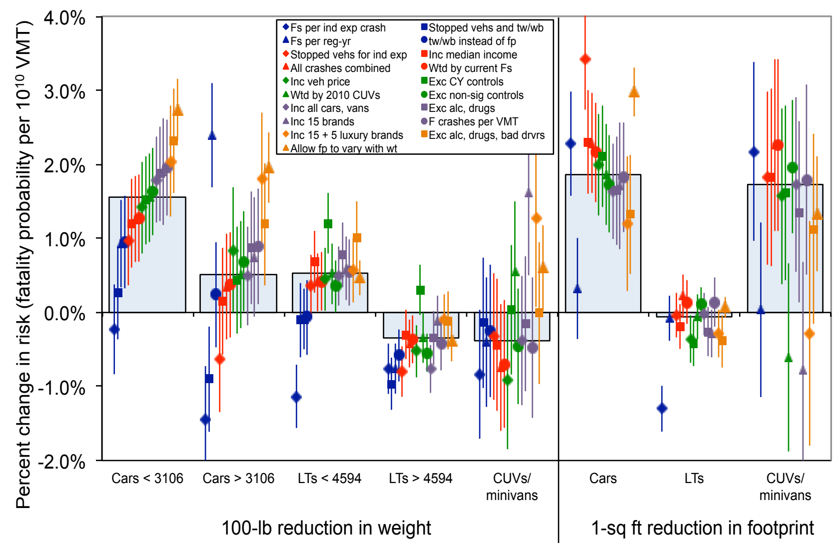


Conclusions from Phase 1 (cont.)

- No correlation between US societal fatality risk and curb weight (or footprint) for:
  - Actual risk
  - Predicted risk, based on all control variables except mass and footprint (➔)
  - Residual risk not explained by variables in regression model

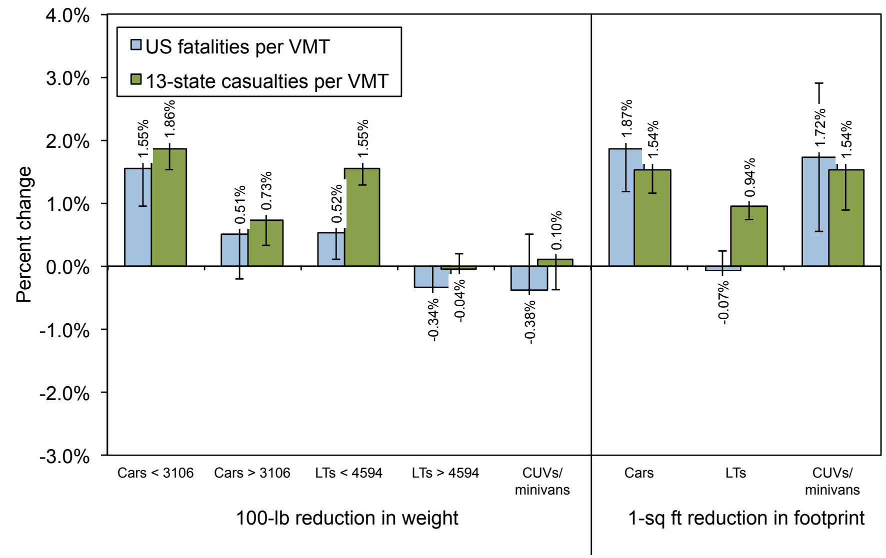


- Effect of mass reduction varies substantially under 19 alternative regression models
  - Alternatives based on different measures of risk, control variables, and data used
  - For lighter-than-average cars:
    - allowing footprint to vary with mass increases estimate to a 2.74% increase in risk
    - replacing footprint with track width and wheelbase reduces estimate to a 0.95% increase in risk
    - measuring risk as fatalities per crash associated with a 0.22% <u>decrease</u> in risk

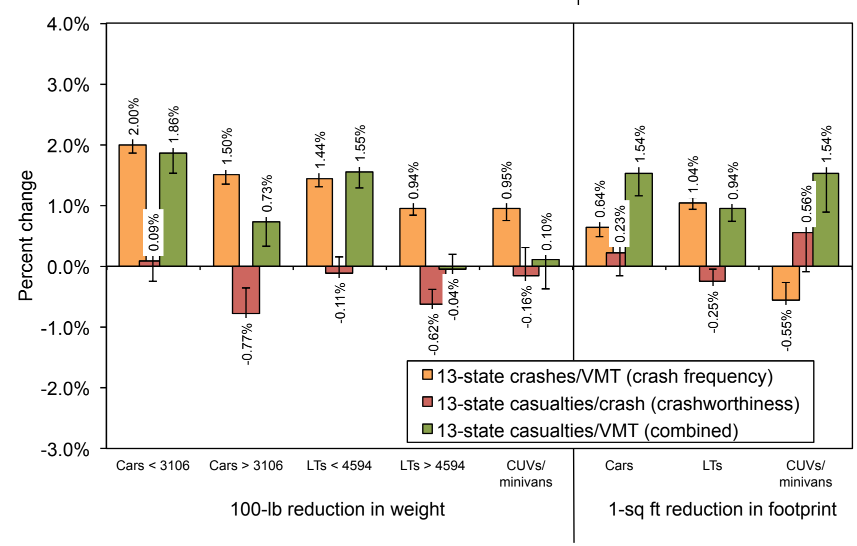


Conclusions from Phase 2

- 13-state societal casualty risk per VMT is comparable to US fatality risk per VMT
  - Mass reduction associated with larger increases in casualty risk, especially for lighter-than-average light trucks

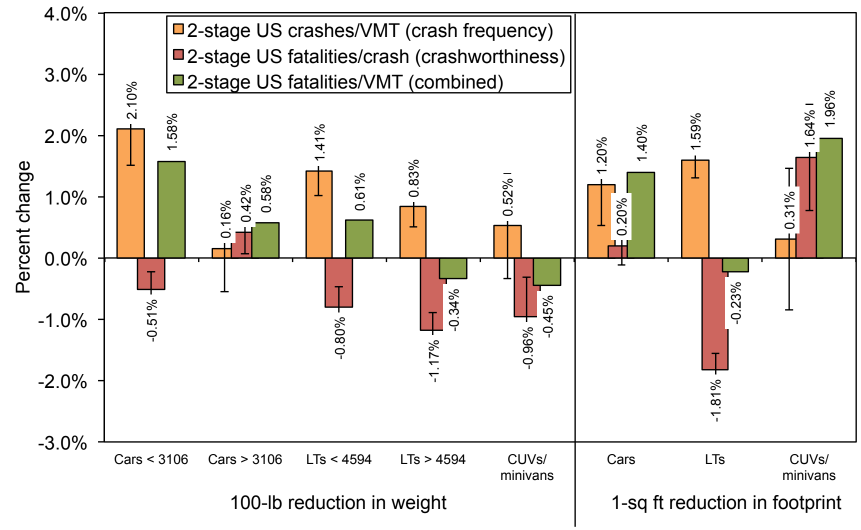


- Mass reduction increases crashes per VMT (crash frequency) but slightly reduces casualties per crash (crashworthiness/compatibility)
  - Contradicts belief that better handling and braking in lighter vehicles results in lower crash frequency
  - Is higher crash frequency in lighter vehicles because of more risky drivers? Further research needed



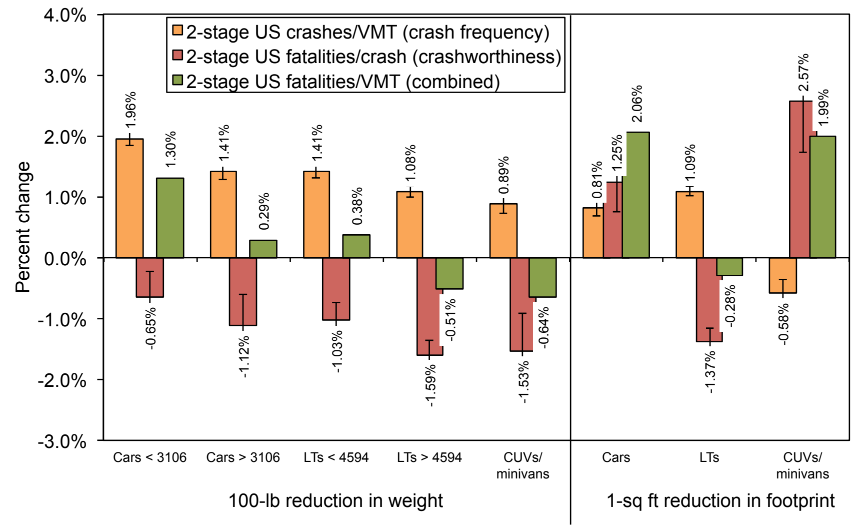
Conclusions from DRI review

- DRI regression model simultaneously estimates effect of mass/footprint reduction on crash frequency, risk per crash, and risk per VMT
  – US fatality data and VMT weights, similar to NHTSA
  – Crash data from only 10 states
  – Sampled 10-state crash data based on distribution of fatalities by state, vehicle, and crash type



- LBNL replicated DRI model, using same data as NHTSA
  – US fatality data and VMT weights
  – Crash data from 13 states
  – No sampling

- Confirms LBNL casualty risk analysis: mass reduction increases crash frequency, but reduces risk per crash



Collaboration and Coordination with Other Institutions

- Worked closely with NHTSA and EPA on data, variables, and methodology used in regression analyses
- Responded to all reviewer comments from formal EPA peer review

Proposed Future Work

- Reconcile discrepancies in DRI and LBNL analyses
- Conduct additional statistical analysis to further illuminate relationship between vehicle mass, size, and safety
  - Account for vehicle handling/braking and driver behavior in crash frequency and risk
  - Study risks of vehicle models after redesign
  - Analyze VMT of consumer subgroups in response to increases in gas prices, and effect on risks per VMT
- Update analyses for midterm review of federal standards

Summary

- Regression analyses can inform regulators on what effect standards may have on safety…
- … but cannot <u>predict</u> that effect, especially given extensive use of new technologies and materials that breaks historical relationships
- Findings
  - Mass reduction is associated with a small increase in risk in lighter-than-average cars only
  - Effect of mass reduction on risk is overwhelmed by other vehicle, driver, and crash characteristics
  - Wide range in risk by vehicle models of similar mass, after accounting for vehicle, driver, and crash differences
  - Mass reduction is associated with an increase in crash frequency, but a decrease in risk per crash
- NHTSA and EPA assumed mass reduction of up to 20% for light trucks and CUVs/minivans with no effect on societal safety, in fuel economy/CO_2 emission standards
  - Up to 10% for large cars, 3.5% for midsize cars, and 0% for compact/subcompact cars

Technical Back-Up Slides

Nine crash types

1. First-event rollover
2. Crash with stationary object
3. Crash with pedestrian/bicycle/motorcycle
4. Crash with heavy-duty vehicle
5. Crash with car/CUV/minivan less than 3,082 lbs
6. Crash with car/CUV/minivan greater than 3,082 lbs
7. Crash with light truck (pickup/SUV/van) less than 4,150 lbs
8. Crash with light truck (pickup/SUV/van) greater than 4,150 lbs
9. Other (mostly crashes involving 3+ vehicles)

- Market saturation of ESC assumed to reduce fatal crashes by:
  - Cars: rollovers by 56%, crashes with objects by 47%
  - Light trucks/CUVs/minivans: rollovers by 74%, crashes with objects by 45%
  - All: all other crashes by 8%

Control variables

- Vehicle
  - UNDRWT00 (lbs less than average mass; 3,106 lbs for cars, 4,594 lbs for LTs)
  - OVERWT00 (lbs more than average mass; 3,106 lbs for cars, 4,594 lbs for LTs)
  - LBS100 (for CUVS/minivans only)
  - FOOTPRINT (wheelbase times track width)
  - Type: two-door car, SUV, heavy-duty (200/300 series) pickup, minivan
  - LT compatibility measure: bumper overlap, blocker beam
  - 5 side airbag variables: rollover curtain, curtain, torso, combo curtain/torso
  - ABS, ESC, AWD, vehicle age, if a brand new vehicle
- Driver
  - Male driver, 8 age variables: years younger/older than 50 (for age groups 14-30, 30-50, 50-70, 70-90, for male and female)
- Crash
  - At night, in rural county (<250 pop/sq mile), on road with 55+ mph speed limit, in high-fatality rate state (25 southern/mountain states, plus KS and MO)
  - Crash occurred in 2002, 2003, 2004, 2005, 2007, or 2008
- Not all variables used for each vehicle or crash type

Alternative regression models

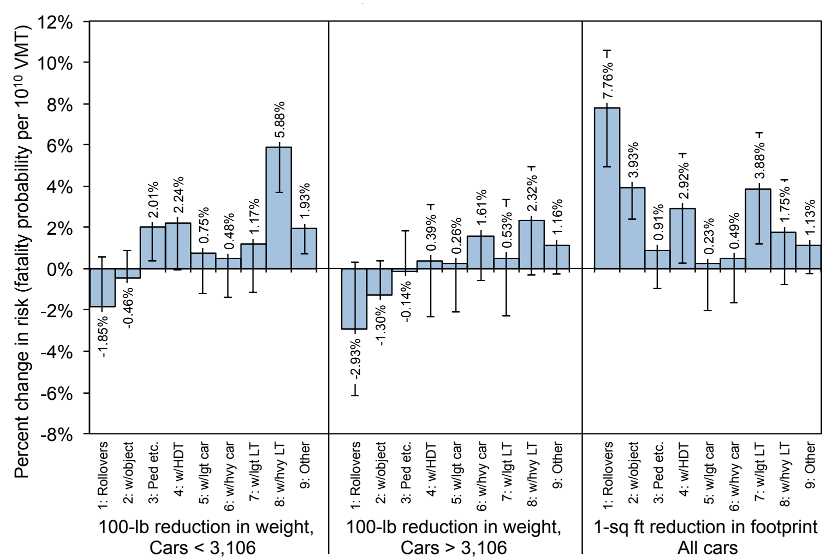
- Alternative definitions of risk
  1. Weighted by current distribution of fatalities (rather than after 100% ESC)
  2. Single regression model across all crash types (rather by crash type)
  3. Fatal crashes (rather than fatalities) per VMT
  4. Fatalities per induced exposure crash (rather than VMT)
  5. Fatalities per registered vehicle-year (rather than VMT)
  6. Market saturation of ESC assumed to reduce
- Alternative control variables/data
  7. Allow footprint to vary with mass (and vice versa)
  8. Account for 14 vehicle manufacturers
  9. Account for 5 additional luxury vehicle brands
  10. Initial vehicle purchase price (based on Polk VIN decoder)
  11. Exclude crashes with alcohol/drugs
  12. Exclude crashes with alcohol/drugs, and drivers with poor driving record
  13. Median household income (based on vehicle zip code, from CA registration data)
  14. Exclude CY variables
- Suggested by peer reviewers
  15. Use stopped instead of non-culpable vehicles from 13-state crash data for induced exposure
  16. Replace footprint with track width and wheelbase
  17. Above two models combined
  18. Reweight CUV/minivans by 2010 sales
  19. Exclude non-significant control variables

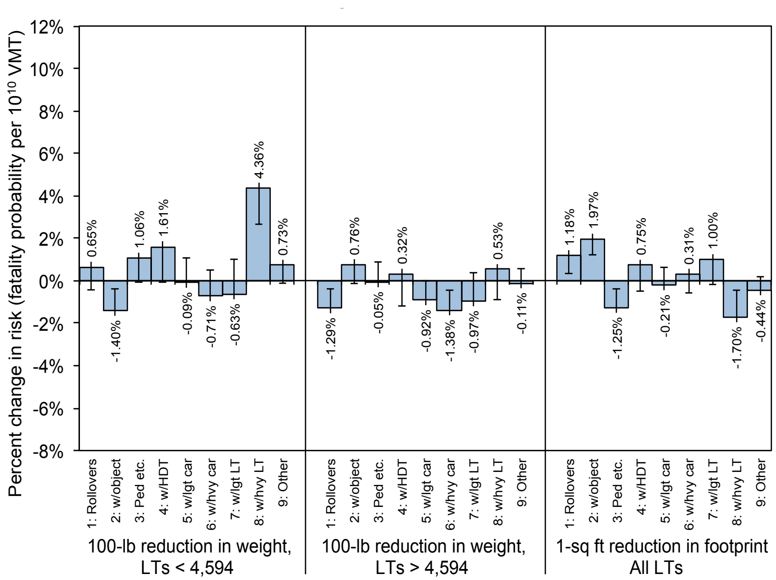
Method to estimate registration and VMT weights

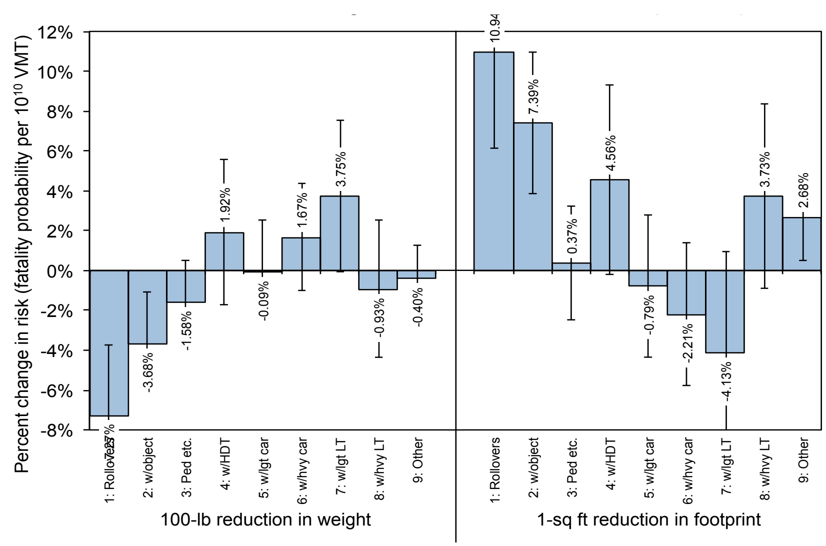
- 2.3 million non-culpable vehicles involved in two-vehicle crashes in 13 states
  - 6 crash states (AL, FL, KS, KY, MO, WY) represent states with high fatality rates
  - 7 crash states (MD, MI, NE, NJ, PA, WA, WI) represent states with low fatality rates
  - DRI proposed using 632,000 stopped vehicles involved in two-vehicle crashes
- Assign weight to each crash vehicle so that sum of weights equals total US vehicle registrations (from RL Polk), by MY and model
- Develop schedule of average annual VMT by vehicle age for cars and trucks, using 2001 National Household Travel Survey
- Use average odometer by make and model (from RL Polk) to adjust annual VMT by make and model

Estimates by crash type

- Mass reduction associated with decrease in risk in rollovers and crashes with objects, for cars and CUVs/minivans
- Footprint reduction associated with highest increase in risk in rollovers and crashes with objects, for cars and CUVs/minivans
- Estimated effects are much smaller for light trucks

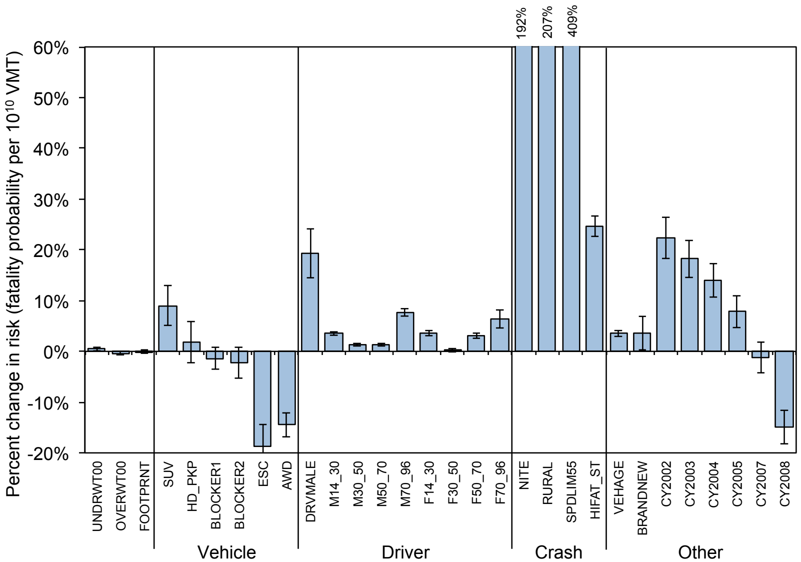




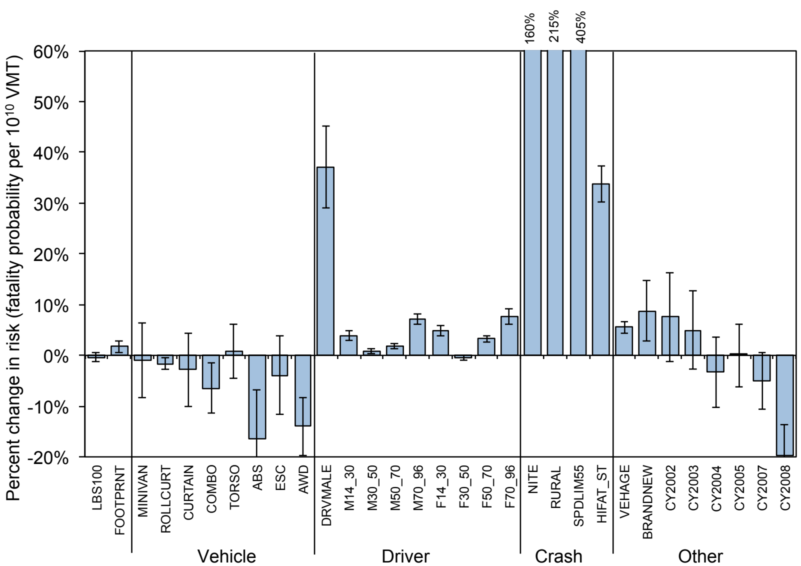


Control variables for LTs, CUV/minivans

- Light trucks

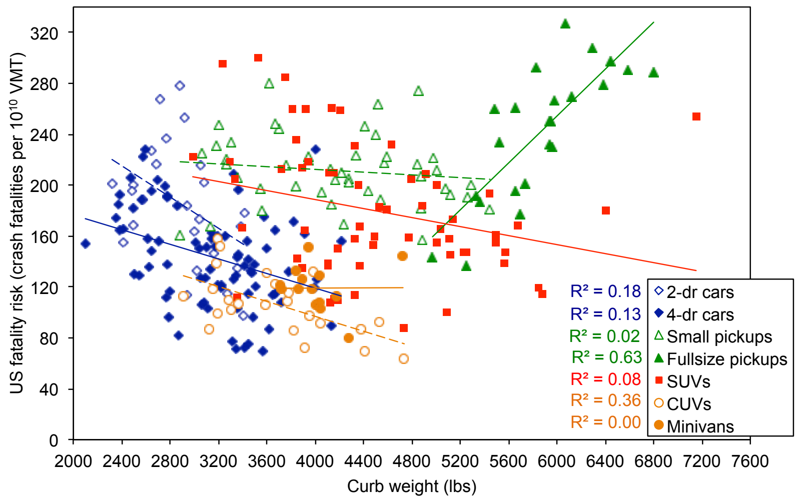


- CUVs/minivans



Actual and residual risk, by model

- Actual US societal fatality risk per VMT, by vehicle model



- Residual US societal fatality risk per VMT, by vehicle model (remaining risk not explained by control variables included in regression model)