Relationships between Mass, Footprint, and Societal Risk in Recent Light-Duty Vehicles

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by

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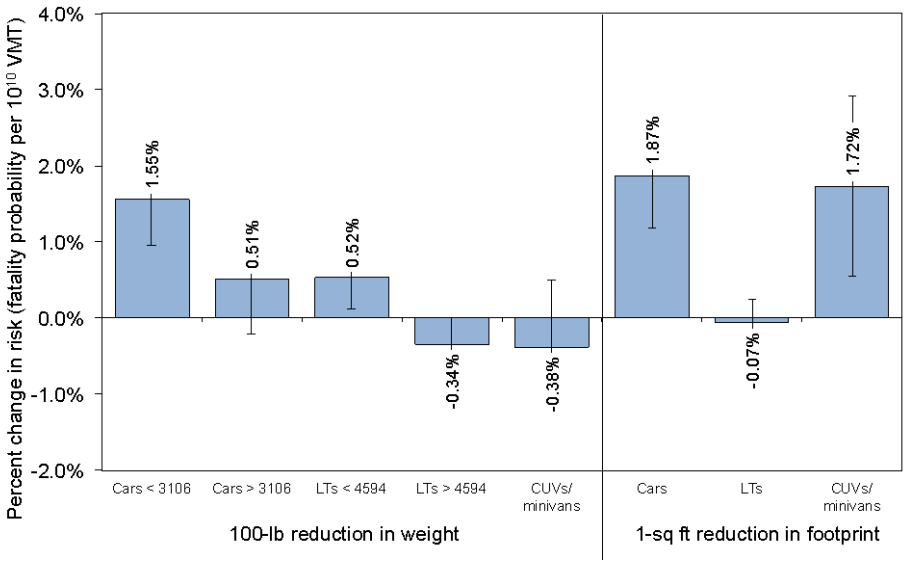
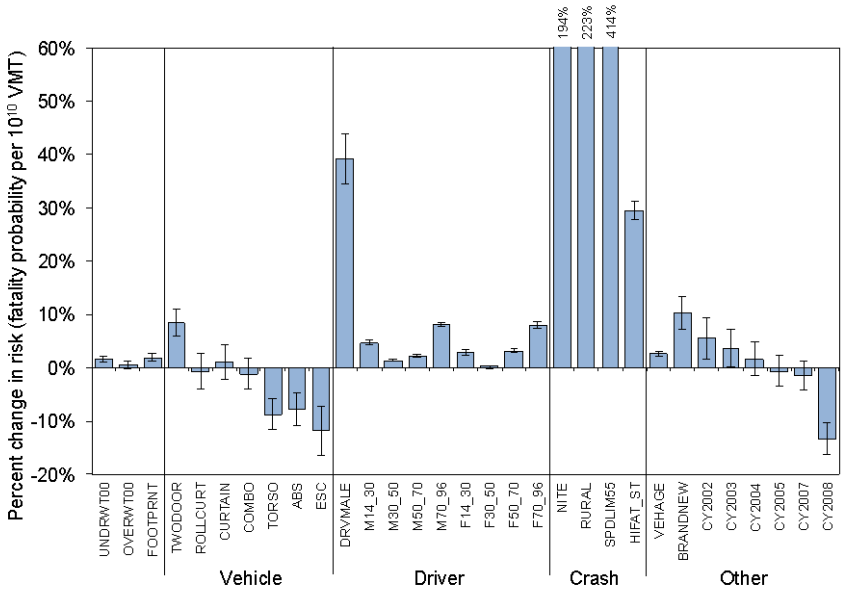
Introduction

- LBNL contracted by US DOE to perform two analyses for MY2000-07 light-duty vehicles in 2002-08:
  - Phase 1: Replicate NHTSA 2012 regression analysis of US societal fatality risk per vehicle mile traveled (VMT)
  - Phase 2: Conduct separate regression analysis of casualty (fatality + serious injury) risk using data from 13 states
- Logistic regression analysis for 27 combinations of vehicle and crash type
  - 3 vehicle types (car, light truck, CUV/minivan)
  - 9 crash types (rollover, stationary object, pedestrian/motorcycle, HDT, four types of LDVs, other)
  - two-piece variable for lighter- and heavier-than-average cars and light trucks
  - ~ 28 variables control for other vehicle (side airbags, ESC, etc.), driver (age and gender), and crash (urban/rural, night, high-speed roads, etc.) characteristics
- Risk is societal, and includes:
  - All occupants of case vehicle
  - All occupants of any crash partner, including pedestrians/motorcyclists
- Statistical analysis estimates the recent historical relationship between vehicle mass or size and societal risk…
  - … but cannot predict this relationship in the future, with new lightweight materials and vehicle redesign

Conclusions from LBNL Phase 1

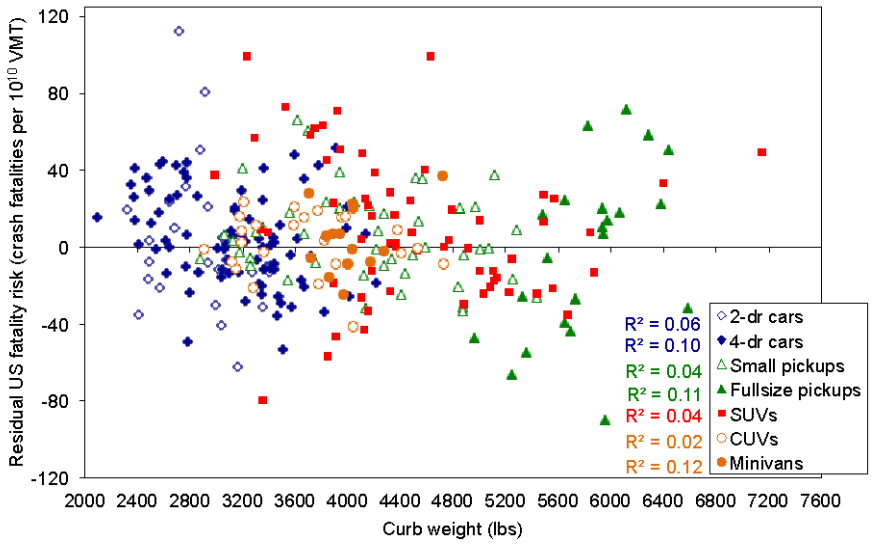
- Baseline NHTSA results: Estimated effect of mass or footprint reduction on societal risk is small
  - Mass reduction associated with a statistically-significant increase in risk only for lighter-than-average cars (1.55%)
  - Footprint reduction associated with increases in risk in cars and CUVs/minivans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



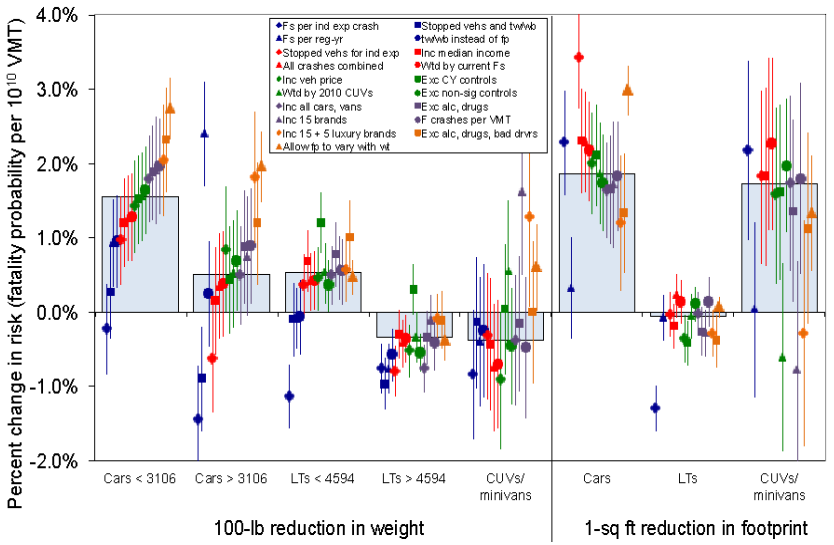


Conclusions from LBNL Phase 1 (cont.)

- 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
  - Estimated effect of mass reduction in lighter-than-average cars ranges from a 2.74% <u>increase</u> to a 0.22% <u>decrease</u> in risk



Alternative regression models in LBNL Phase 1

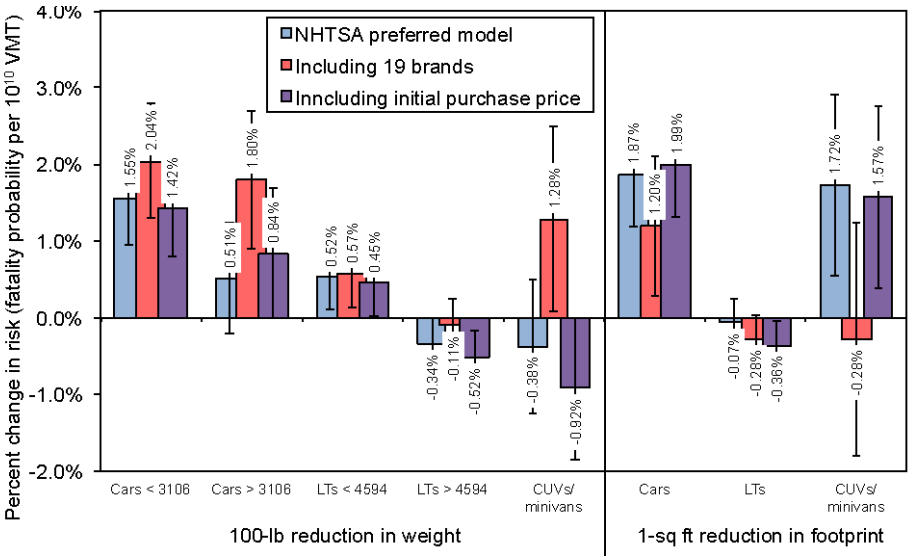
- Alternative definitions of risk
  1. Weighted by current distribution of fatalities (rather than after 100% ESC)
  2. Single regression model across all crash types (rather by crash type)
  3. Fatal crashes (rather than fatalities) per VMT
  4. Fatalities per induced exposure crash (rather than VMT)
  5. Fatalities per registered vehicle-year (rather than VMT)
- Alternative control variables/data
  6. Allow footprint to vary with mass (and vice versa)
  7. Account for 14 vehicle manufacturers
  8. Account for 14 manufacturers + 5 additional luxury vehicle brands
  9. Account for initial vehicle purchase price (based on Polk VIN decoder)
  10. Exclude CY variables
  11. Exclude crashes with alcohol/drugs
  12. Exclude crashes with alcohol/drugs, and drivers with poor driving record
  13. Account for median household income (based on vehicle zip code, from CA DMV data)
  14. Include sports, police, and all-wheel drive cars, and full size vans
- Suggested by DRI and 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

Alternative regression models in LBNL Phase 1 (cont.)

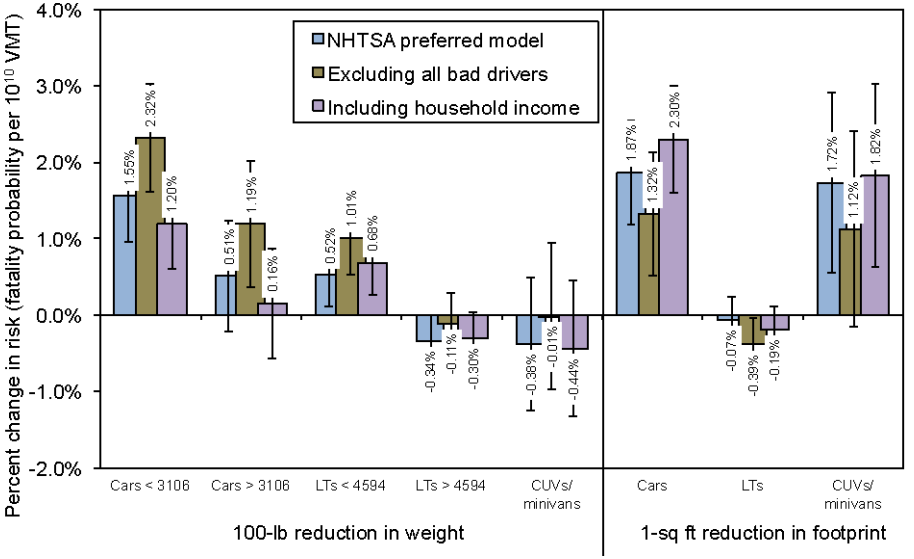
- No correlation between residual risk and mass by vehicle model; differences in residual risk by model due to
  - Differences in vehicle design (other than mass, footprint, safety features)?
  - Differences in driver behavior (other than age and gender)?
- Two measures of vehicle design
  - 19 vehicle brands (14 manufacturers + 5 luxury brands)
  - Initial vehicle purchase price
- Two measures of driver behavior
  - Exclude crashes with alcohol/drug use, poor driving in current crash, poor driving record
  - Median household income by vehicle model (using CA registration data)
- Alternative measure of risk
  - US fatalities per induced exposure crash (crashworthiness/compatibility)

Alternative models accounting for vehicle and driver differences in LBNL Phase 1

- Alternative models accounting for vehicle differences
  - Including 19 vehicle brands
    - Increases detrimental effect of mass reduction in cars and CUVs/minivans
    - Reduces detrimental effect of footprint reduction in all three vehicle types
  - Including vehicle price
    - Slightly increases detrimental effect of mass reduction in heavier cars, increases beneficial effect of mass reduction in CUVs/minivans
    - Increases beneficial effect of footprint reduction in light trucks

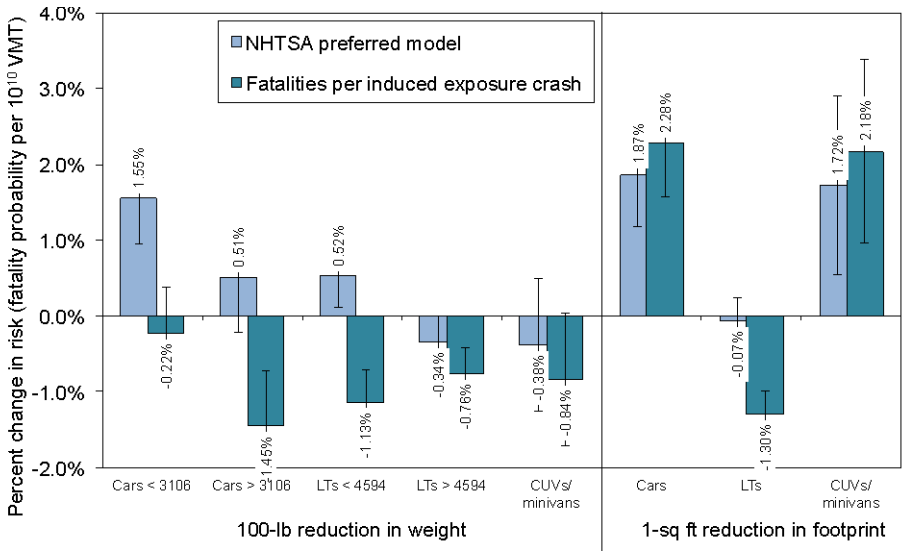


- Alternative models accounting for driver differences
  - Excluding crashes with alcohol/drug use and poor driving
    - Increases detrimental effect of mass reduction in all five vehicle types
    - Reduces detrimental effect of footprint reduction in all three vehicle types
  - Including household income
    - Reduces detrimental effect of mass reduction in cars
    - Increases detrimental effect of footprint reduction in cars



Alternative measure of risk in LBNL Phase 1

- Alternative measure of risk
  - US fatalities per induced exposure crash (crashworthiness/compatibility)
    - Mass reduction in all five vehicle types associated with reduction in fatality risk per crash

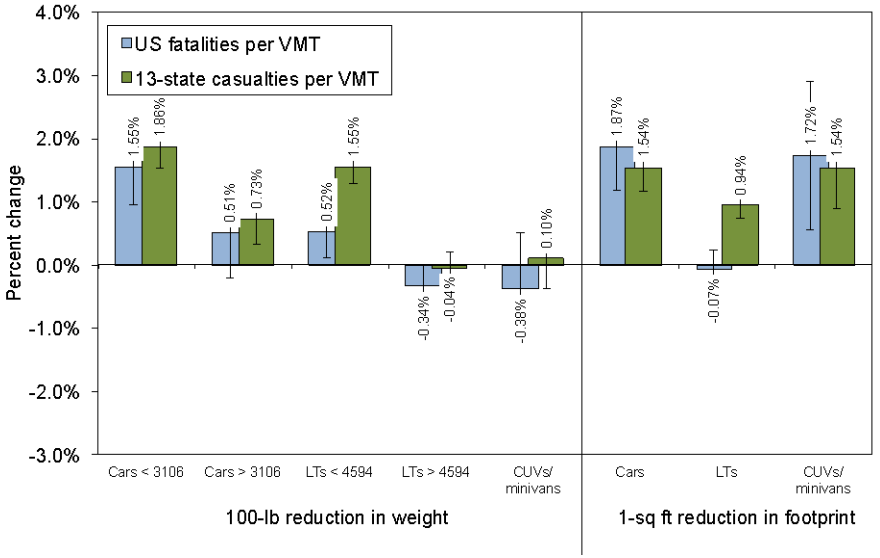


LBNL Phase 2 analysis

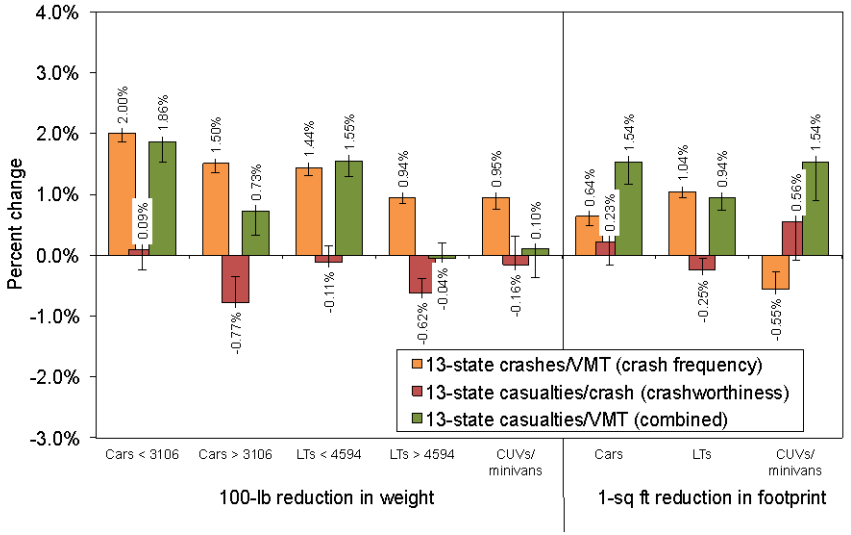
- LBNL Phase 2 analysis
  - All data from police-reported crashes in 13 states
  - Numerator: fatalities or casualties (fatalities + serious injuries)
  - Denominator: all crash-involved vehicles
  - Result: 13-state fatalities or casualties per crash
  - Analysis of two components of casualties per VMT:
    - Crash frequency: crashes per mile traveled, using NHTSA weights
    - Crashworthiness/compatibility: casualties per crash
- Drawbacks of Phase 2 analysis
  - 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

Conclusions from LBNL 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

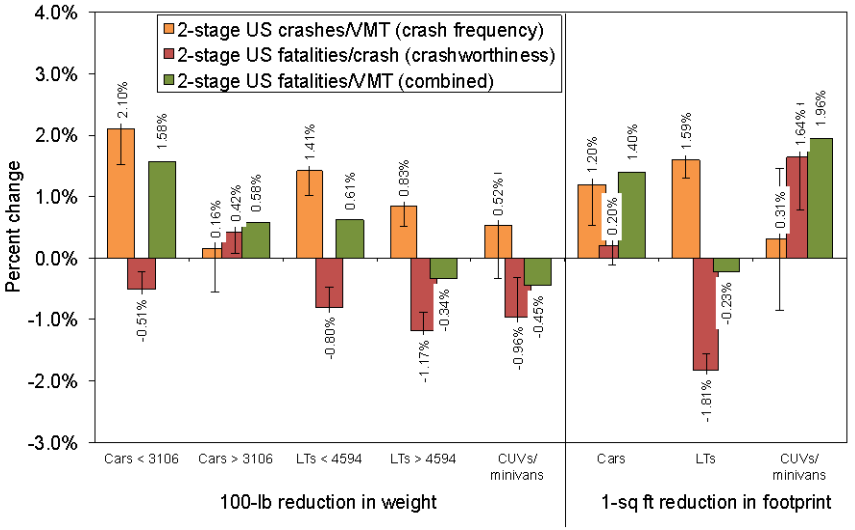


- Mass reduction increases crashes per VMT (crash frequency) but slightly reduces casualties per crash (crashworthiness/compatibility)
  - Contradicts belief that better handling and braking in lighter vehicles results in lower crash frequency
  - Is higher crash frequency in lighter vehicles because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



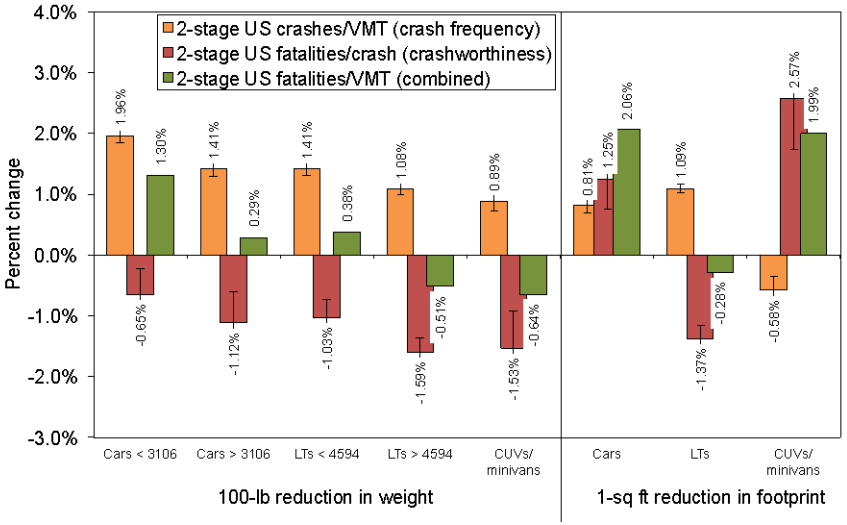
Conclusions from LBNL review of DRI 2013

- 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 from 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



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 predict 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
  - Accounting for vehicle design or driver behavior changes estimates depending on variables used
  - Mass reduction is associated with an increase in crash frequency, but a decrease in risk per crash

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

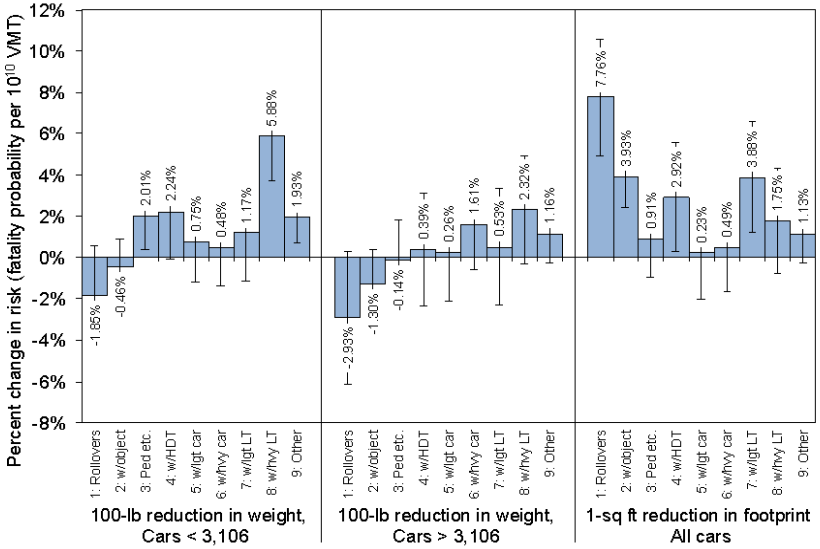
- Vehicle
  - UNDRWT00 (lbs less than average mass; 3,106 lbs for cars, 4,594 lbs for LTs)
  - OVERWT00 (lbs more than average mass; 3,106 lbs for cars, 4,594 lbs for LTs)
  - LBS100 (for CUVS/minivans only)
  - FOOTPRINT (wheelbase times track width)
  - Type: two-door car, SUV, heavy-duty (200/300 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

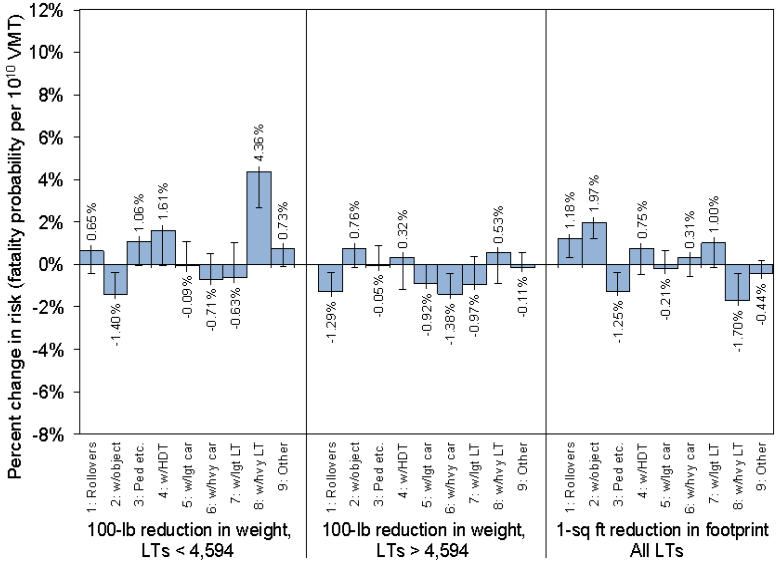
Method to estimate registration and VMT weights

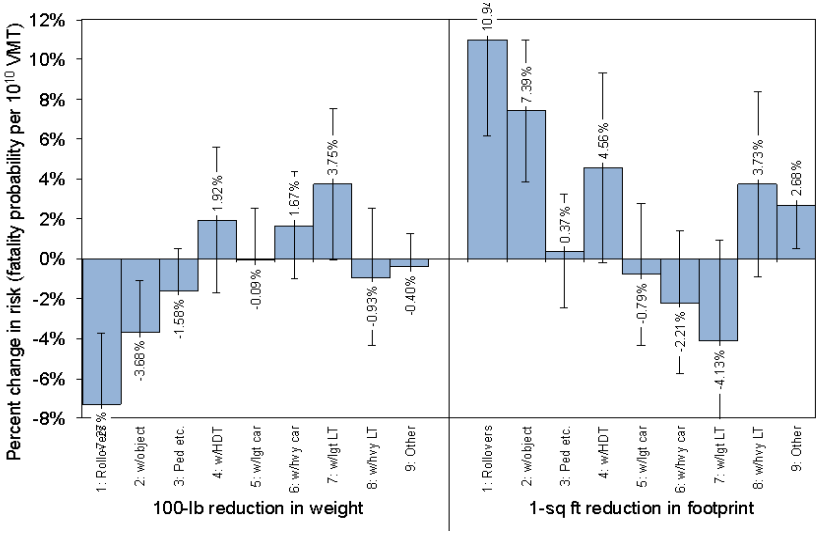
- 2.3 million non-culpable vehicles involved in two-vehicle crashes in 13 states
  - 6 crash states (AL, FL, KS, KY, MO, WY) represent states with high fatality rates
  - 7 crash states (MD, MI, NE, NJ, PA, WA, WI) represent states with low fatality rates
  - DRI proposed using 632,000 stopped vehicles 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

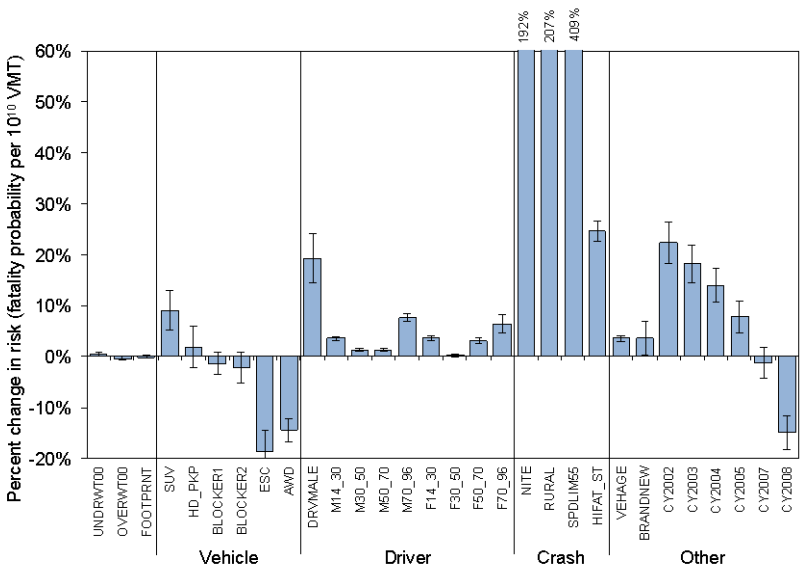




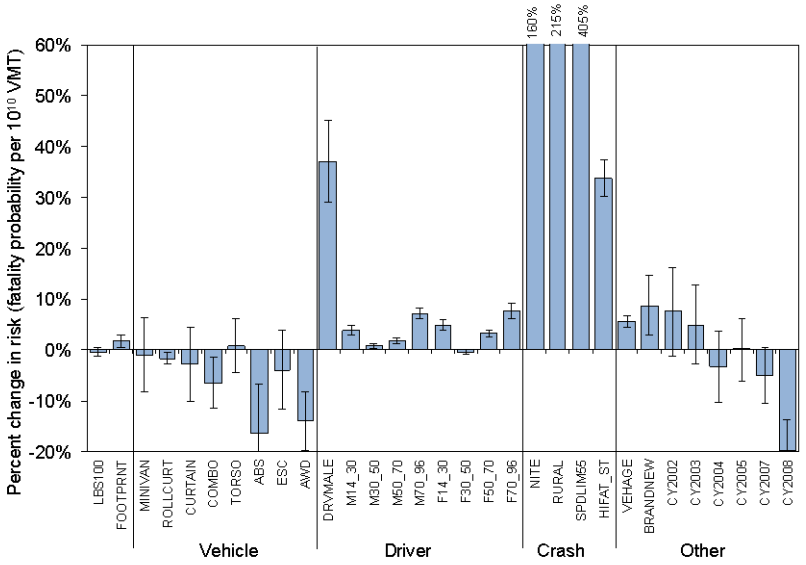


Control variables for light trucks, CUV/minivans

- Light trucks

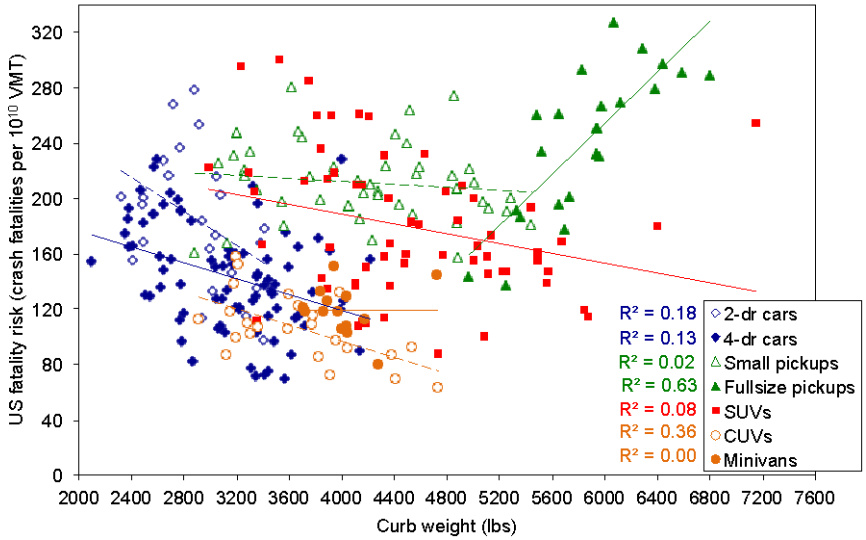


- CUVs/minivans

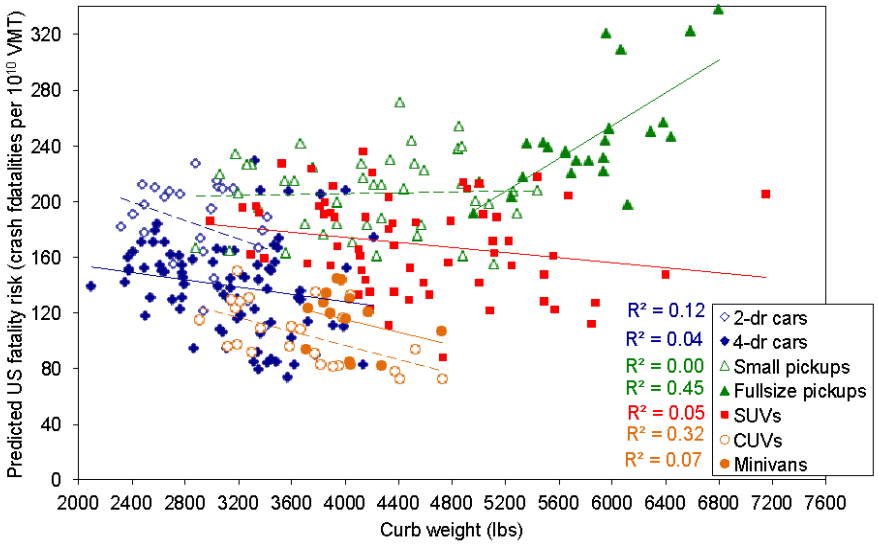


Actual and predicted risk, by model

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

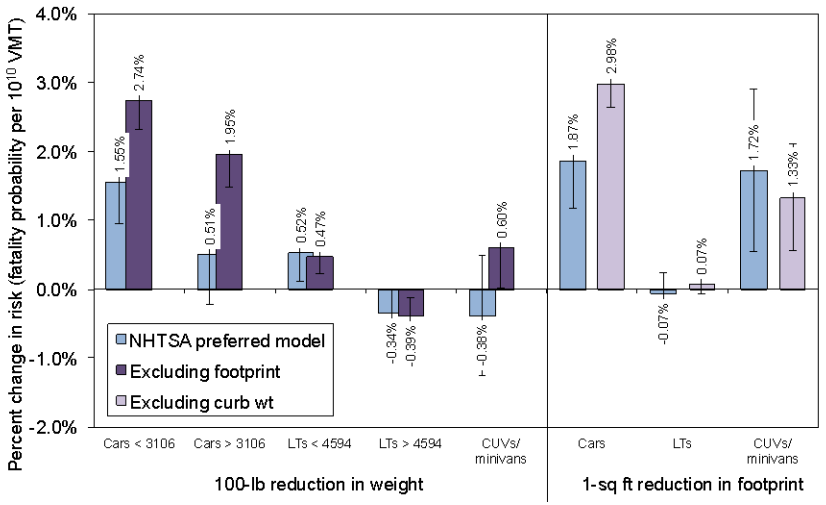


- Predicted US societal fatality risk per VMT, based on all control variables except mass and footprint, by vehicle model



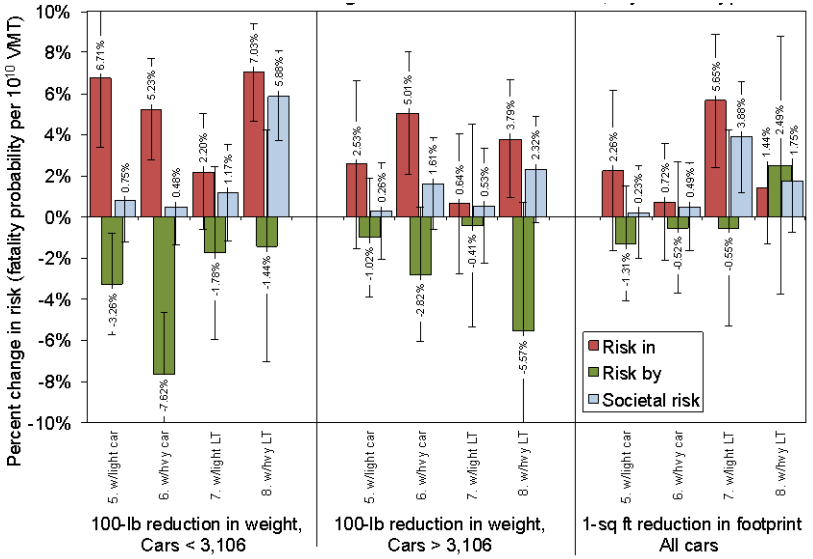
Alternative regression models

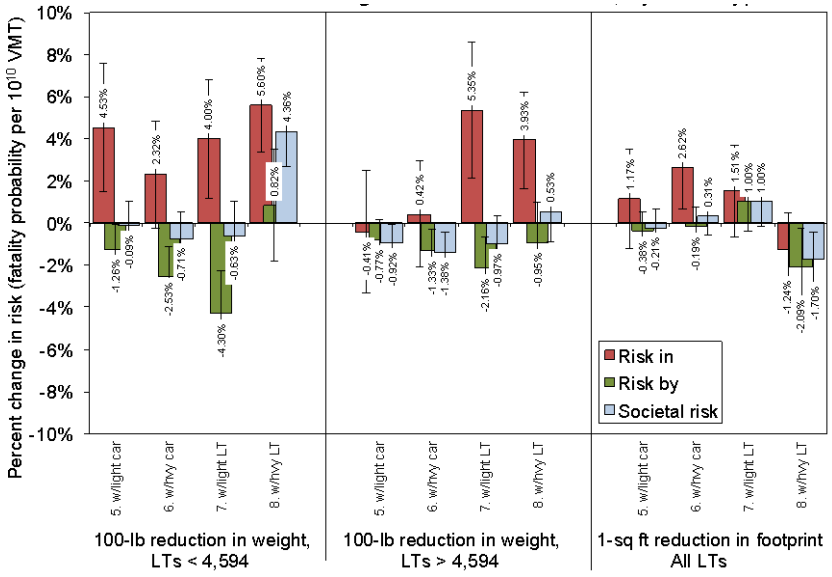
- Alternative models
  - Allowing footprint to vary with mass reduction
    - Increases detrimental effect of mass reduction in cars and CUVs/minivans
  - Allowing mass to vary with footprint reduction
    - Increases detrimental effect of footprint reduction in cars

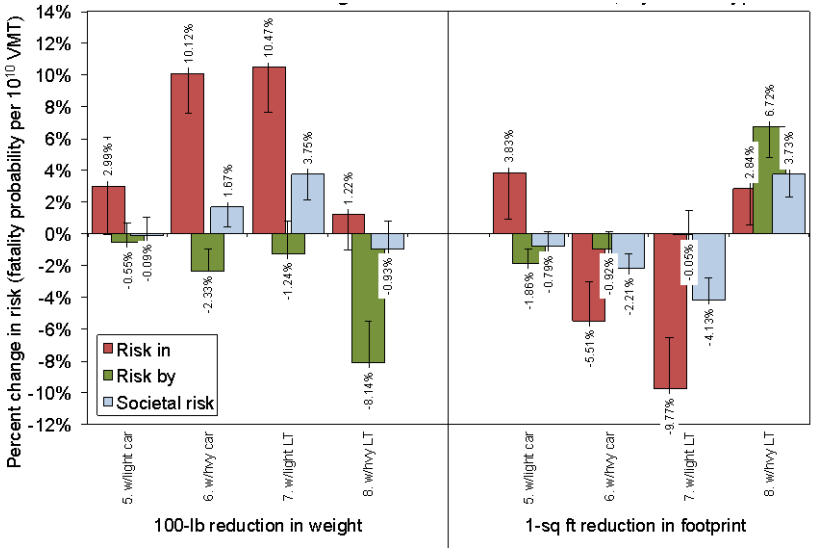


Risk in and risk by estimates by crash type

- Risk in = fatality risk to occupants in subject vehicle
- Risk by = fatality risk to occupants in crash partner
- Risks shown are only for crashes between two light-duty vehicles
- In general mass reduction increases risk in, but reduces risk by, for all vehicle and crash types







Publications and presentations

- Reports
  - Wenzel, Tom. 2012. ***Assessment of NHTSA's Report "Relationships between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs"***. LBNL-5698E.
  - Wenzel, Tom. 2012. ***An Analysis of the Relationship between Casualty Risk per Crash and Vehicle Mass and Footprint for Model Year 2000-2007 Light-Duty Vehicles***. LBNL-5697E
  - Systems Research and Application Corporation. 2012. ***Peer Review of LBNL Statistical Analysis of the Effect of Vehicle Mass & Footprint Reduction on Safety (LBNL Phase 1 and 2 Reports)***. EPA-420-R-12-020. (includes Tom Wenzel's responses to peer reviewer comments)
  - Wenzel, Tom. 2013. ***Assessment of DRI's Two-Stage Logistic Regression Model Used to Simultaneously Estimate the Relationship between Vehicle Mass or Size Reduction and U.S. Fatality Risk, Crashworthiness/Compatibility, and Crash Avoidance***. Draft report.
- Presentations
  - Wenzel, Tom. 2012. "Relationships between Vehicle Mass, Footprint, and Societal Risk." Poster presented at TRB UTC Spotlight Conference on Sustainable Energy and Transportation, Washington DC, November 8-9.
- Journal articles
  - Wenzel, Tom. 2013. "The Estimated Effect of Mass or Footprint Reduction in Recent Light-Duty Vehicles on U.S. Societal Fatality Risk per Vehicle Mile Traveled." Submitted to *Accident Analysis and Prevention*.
  - Wenzel, Tom. 2013. "The Effect of Recent Trends in Vehicle Design on U.S. Societal Fatality Risk per Vehicle Mile Traveled, and Their Projected Future Relationship with Vehicle Mass." *Accident Analysis and Prevention* 56, 71-81.
  - Wenzel, Tom. 2013. "The Relationship between U.S. Societal Fatality Risk per Vehicle Mile Traveled and Vehicle Mass, by Vehicle Type and Model." Submitted to *Accident Analysis and Prevention*.