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

NRC Committee Meeting: Assessment of Technologies for Improving Fuel Economy of Light-Duty Vehicles: Phase 2
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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 <u>historical</u> relationship between vehicle mass or size and societal risk…
  - … but cannot predict this relationship in the <u>future</u>, with new lightweight materials and vehicle redesign

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

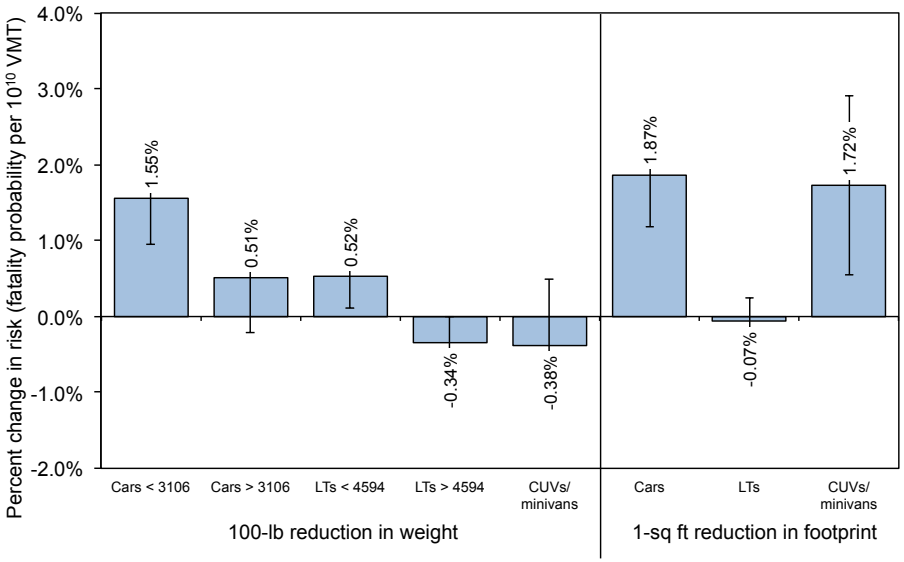
- Vehicle
  - UNDRWT00 (100 lbs less than avg mass; 3,106 lbs for cars, 4,594 lbs for LTs)
  - OVERWT00 (100 lbs more than avg mass; 3,106 lbs for cars, 4,594 lbs for LTs)
  - LBS100 (in 100 lbs, for CUVS/minivans only)
  - FOOTPRINT (in square feet, wheelbase times track width)
  - Type: two-door car, 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

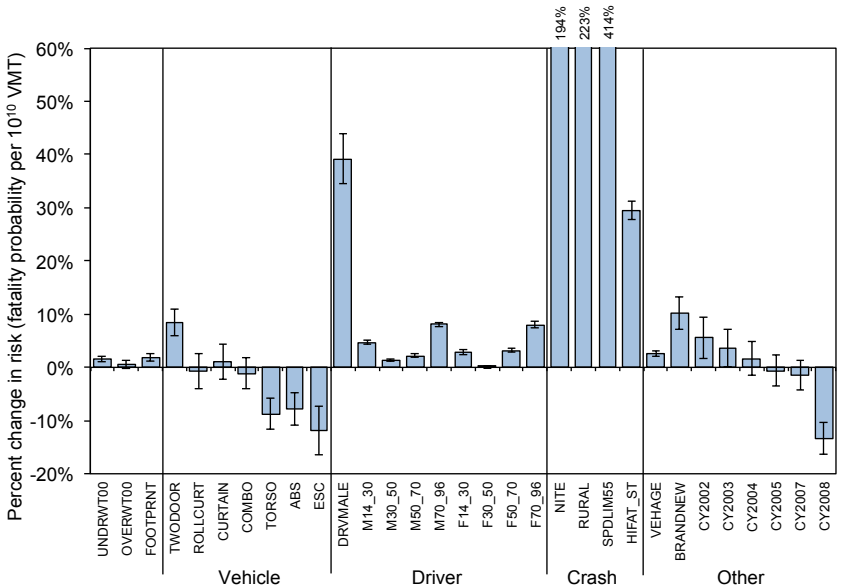
- 2.3 million non-culpable vehicles involved in two-vehicle crashes in 13 states
  - 6 crash states (AL, FL, KS, KY, MO, WY) represent states with high fatality rates
  - 7 crash states (MD, MI, NE, NJ, PA, WA, WI) represent states with low fatality rates
  - DRI proposed using 632,000 stopped vehicles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

Conclusions from LBNL Phase 1

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

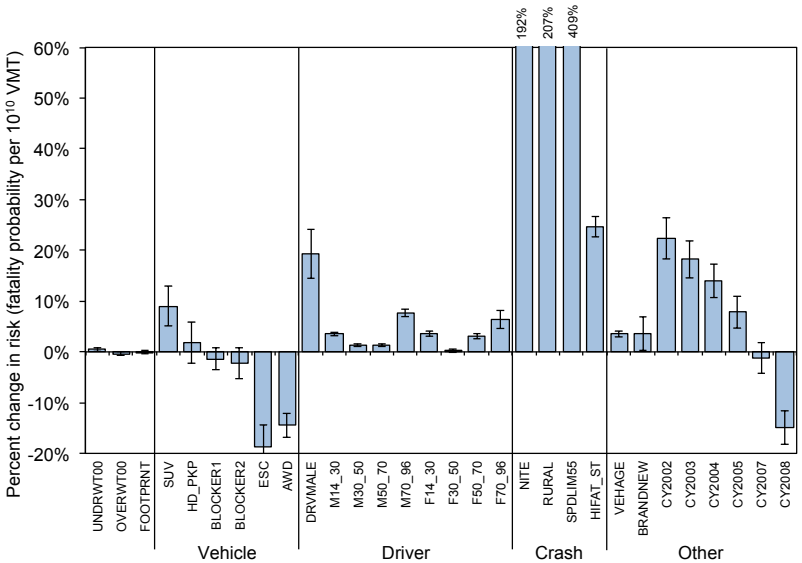


- Effect of mass or footprint reduction is overwhelmed by other factors (results for cars shown)
  - Other vehicle characteristics nearly 10x larger
  - Driver gender up to 25x larger
  - Certain crash characteristics over 200x larger

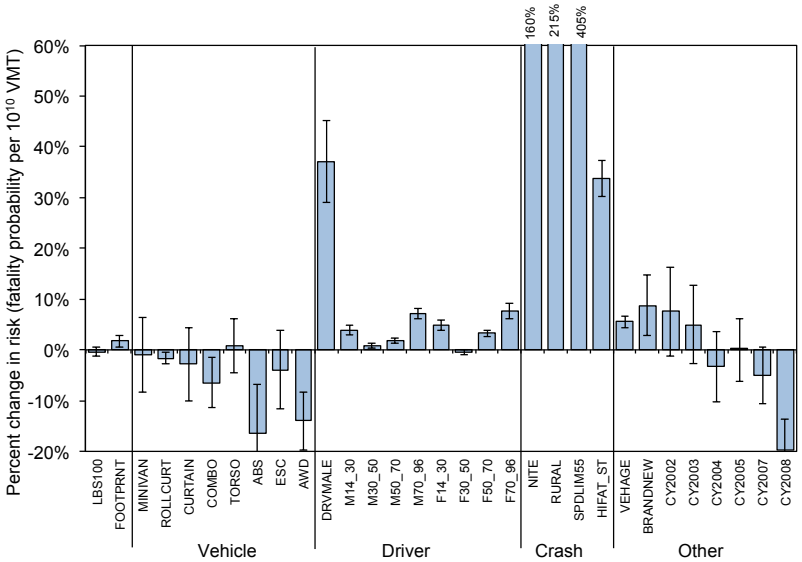


Control variables for light trucks, CUV/minivans

- Light trucks



- CUVs/minivans

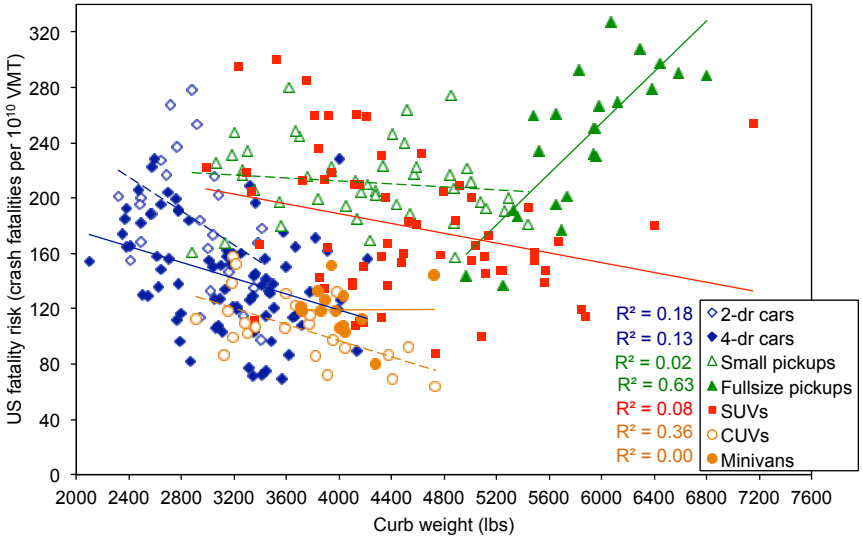


Analysis by vehicle model

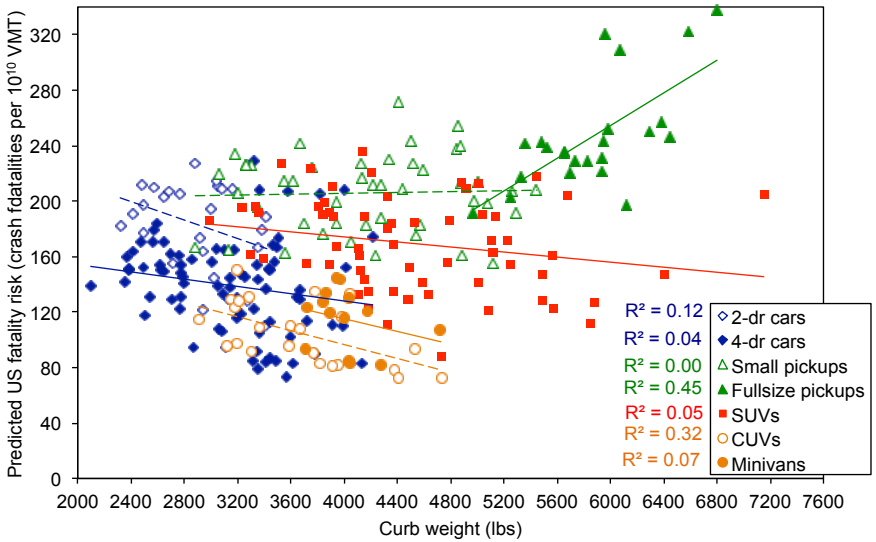
- Logistic regression does not include a statistic for "goodness of fit" akin to R^2 in linear regression (how much of the variability in the data is explained by the regression model)
  - SAS includes a "pseudo-R^2", although different techniques give wildly different estimates
  - SAS pseudo-R^2 is less than 0.10 in NHTSA baseline regression
- LBNL analyzed relationship between mass and risk by vehicle model, using linear regression
  - Run logistic regression including all variables except mass and footprint
  - Estimate predicted risk, by applying coefficients for vehicle, driver and crash characteristics of induced exposure vehicles (and VMT)
  - (Residual risk = actual risk – predicted risk)
  - Run logistic regression including all variables
  - Estimate standardized risk for a 50-year old male driving a 4-year old vehicle in the day in a non-rural county on a high-speed road in a low-risk state
  - Adjusted risk = standardized risk * (actual risk / predicted risk)

Actual and predicted risk, by model

- Actual US societal fatality risk per VMT, by vehicle model
  - On average, societal fatality risk tends to decrease as mass increases (except for full size pickups)
  - But very low correlation between societal fatality risk and mass (or footprint) by vehicle model

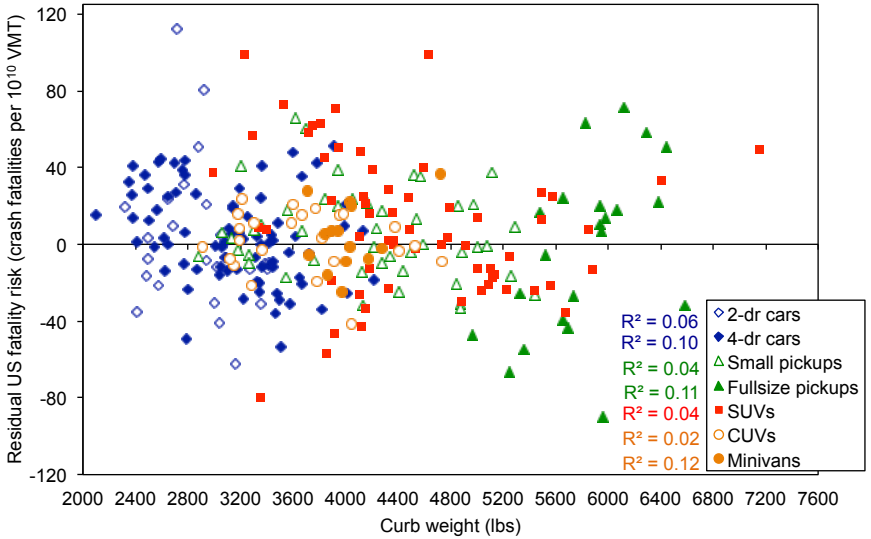


- Predicted US societal fatality risk per VMT, based on all control variables except mass and footprint, by vehicle model

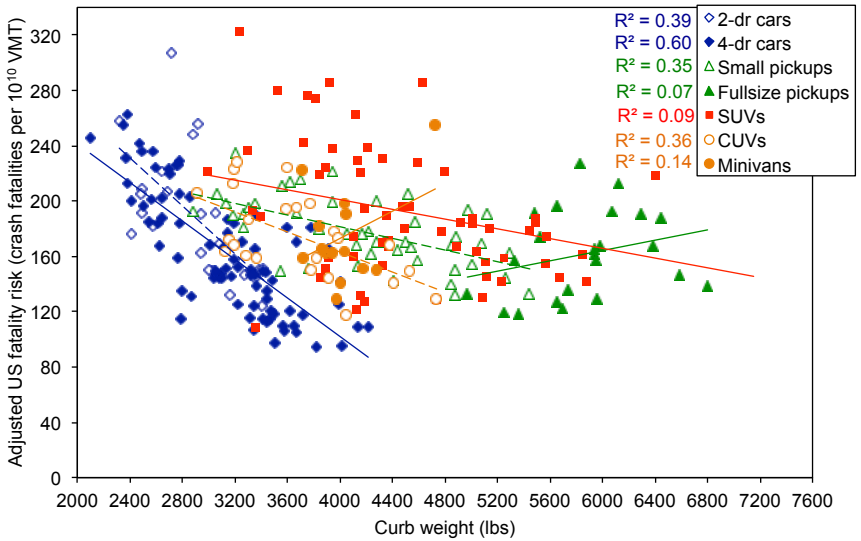


Residual and adjusted risk, by model

- Residual risk not explained by variables in regression
  - Essentially no correlation between residual fatality risk and curb weight (or footprint)
  - Whatever factors "explain" remaining risk not captured by regression model, they are not correlated with vehicle mass



- Adjusted risk
  - Risk standardized for same driver and crash circumstances
  - Adjusted risk = standardized risk * (actual risk / predicted risk)
  - Adjusted risk correlated with curb weight 4-door cars (R^2=0.60), but still large range in risk for models with similar footprint
  - Essentially no correlation between adjusted risk and curb weight (or footprint) for other vehicle types



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

Results of alternative regression models

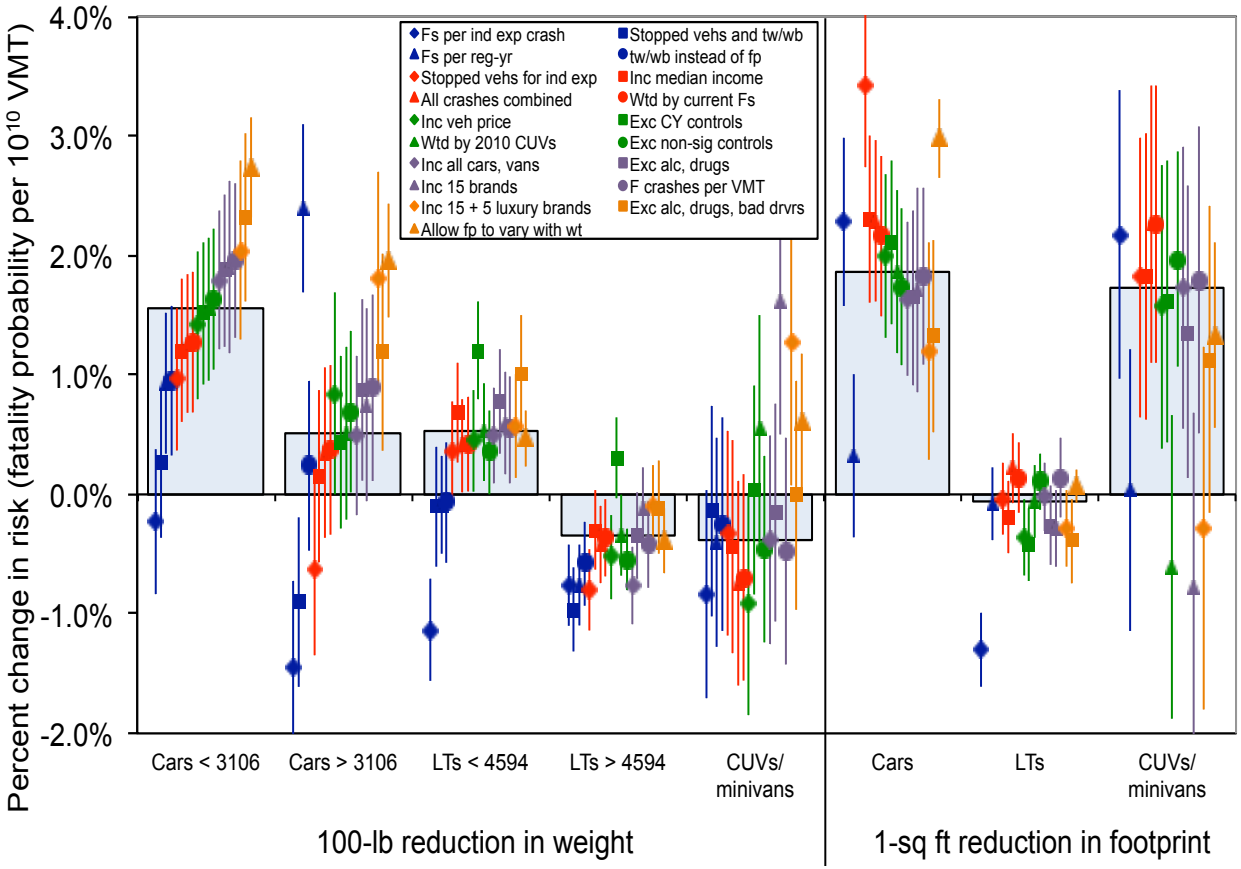
Regression model	Estimated effect of a 100-lb reduction in mass					Estimated effect of a 1-sq foot reduction in footprint		
	Cars		Light trucks		CUVs/ minivans		Light trucks	CUVs/ minivans
	Light	Heavy	Light	Heavy		Cars		
NHTSA baseline	1.55%*	0.51%	0.52%*	-0.34%*	-0.38%	1.87%*	-0.07%	1.72%*
Alternative 1	1.27%*	0.37%	0.42%*	-0.36%*	-0.70%	2.16%*	0.14%	2.25%*
Alternative 2	1.26%*	0.35%	0.41%*	-0.42%*	-0.74%	2.28%*	0.22%	2.26%*
Alternative 3	2.74%*	1.95%*	0.47%*	-0.39%*	0.60%*	2.98%*	0.07%	1.33%*
Alternative 4	1.95%*	0.89%*	0.54%*	-0.42%*	-0.47%	1.83%*	0.14%	1.79%*
Alternative 5	-0.22%	-1.45%*	-1.13%*	-0.76%*	-0.84%	2.28%*	-1.30%*	2.18%*
Alternative 6	0.93%*	2.40%*	-0.09%	-0.76%*	-0.40%	0.32%	-0.08%	0.03%
Alternative 7	1.90%*	0.75%	0.59%*	-0.11%	1.62%*	1.71%*	-0.29%	-0.77%
Alternative 8	2.04%*	1.80%*	0.57%*	-0.11%	1.28%*	1.20%*	-0.28%	-0.28%
Alternative 9	1.42%*	0.84%	0.45%*	-0.52%*	-0.92%	1.99%*	-0.36%*	1.57%*
Alternative 10	1.52%*	0.43%	1.20%*	0.30%	0.03%	2.11%*	-0.42%*	1.61%*
Alternative 11	1.88%*	0.88%*	0.78%*	-0.35%	-0.16%	1.65%*	-0.26%	1.36%*
Alternative 12	2.32%*	1.19%*	1.01%*	-0.11%	-0.01%	1.32%*	-0.39%*	1.12%
Alternative 13	1.20%*	0.16%	0.68%*	-0.30%	-0.44%	2.30%*	-0.19%	1.82%*
Alternative 14	1.79%*	0.49%	0.49%*	-0.77%*	-0.38%	1.64%*	-0.02%	1.72%*
Alternative 15	0.97%*	-0.63%	0.35%	-0.80%*	-0.33%	3.43%*	-0.03%	1.81*%
Alternative 16	0.95%*	0.24%	-0.07%	-0.58%*	-0.25%	—	—	—
Alternative 17	0.26%	-0.90%*	-0.10%	-0.97%*	-0.14%	—	—	—
Alternative 18	1.55%*	0.51%	0.52%*	-0.34%*	0.55%	1.87%*	-0.07%	-0.61%
Alternative 19	1.63%*	0.69%*	0.35%*	-0.54%*	-0.46%	1.73%*	0.11%	1.97*%

Note: Light cars weight less than 3,106 lbs, heavy cars weigh more than 3,106 lbs; light light trucks weigh less than 4,594 lbs, heavy light trucks weigh more than 4,594 lbs.

* statistically significant at the 95% level.

Results of alternative regression models (cont.)

- 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



LBNL Phase 2 analysis

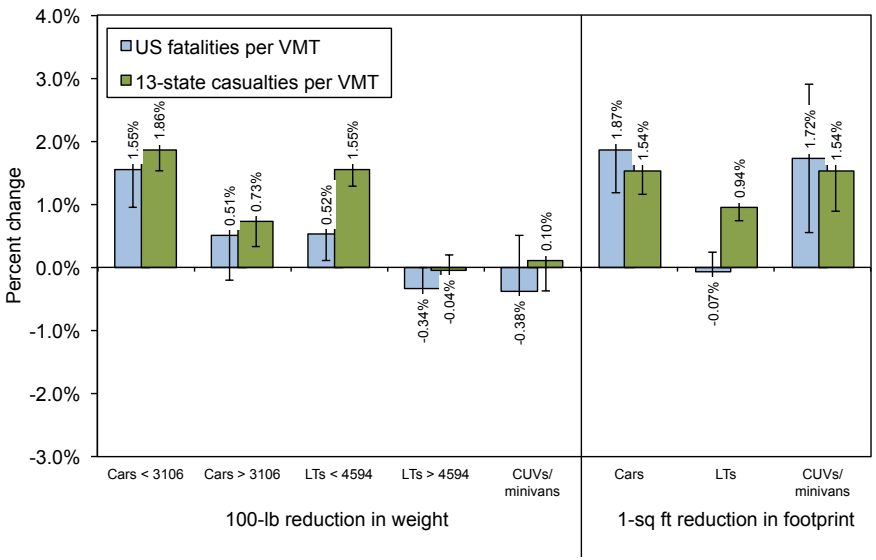
- LBNL Phase 2 analysis
  - All data from police-reported crashes in 13 states
  - Numerator: fatalities or casualties (fatalities + serious injuries)
  - Denominator: all crash-involved vehicles
  - Result: 13-state fatalities or casualties per crash
  - Analysis of two components of casualties per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

$$\frac{\text{casualties}}{\text{VMT}} = \frac{\text{crashes}}{\text{VMT}} + \frac{\text{casualties}}{\text{crash}}$$

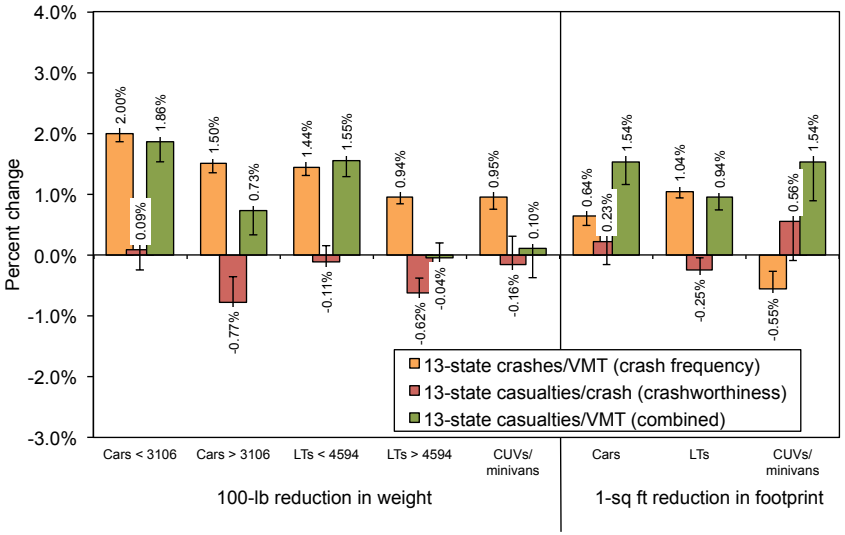
- Drawbacks of Phase 2 analysis
  - Limited to 13 states that provide Vehicle Identification Number (VIN)
    - Does relationship between weight/size and risk vary by state?
    - Are 13 states representative of national relationship?
  - Not enough fatalities in 13 states to also get robust results 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

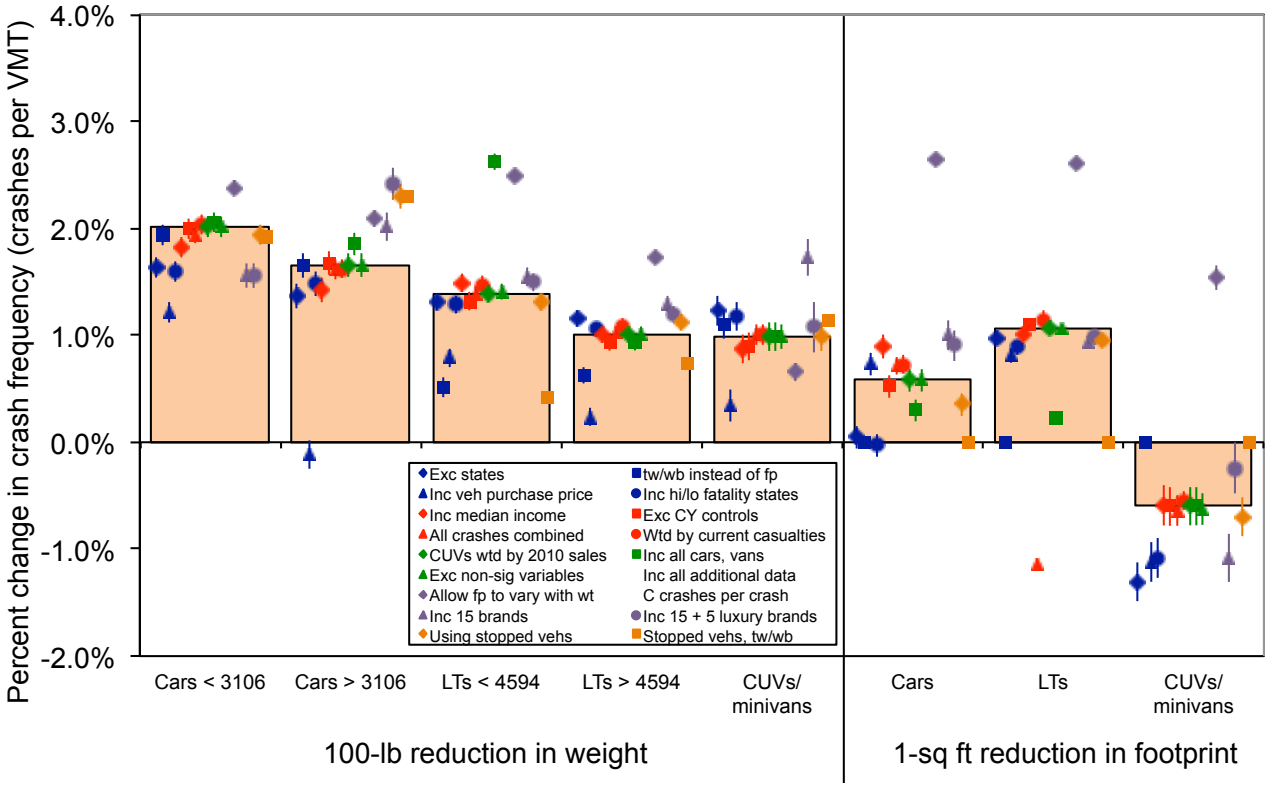


- Mass reduction increases crashes per VMT (crash frequency) but slightly reduces casualties per crash (crashworthiness/compatibility)
  - Contradicts belief that better handling and braking in lighter vehicles results in lower crash frequency
  - Is higher crash frequency in lighter vehicles because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



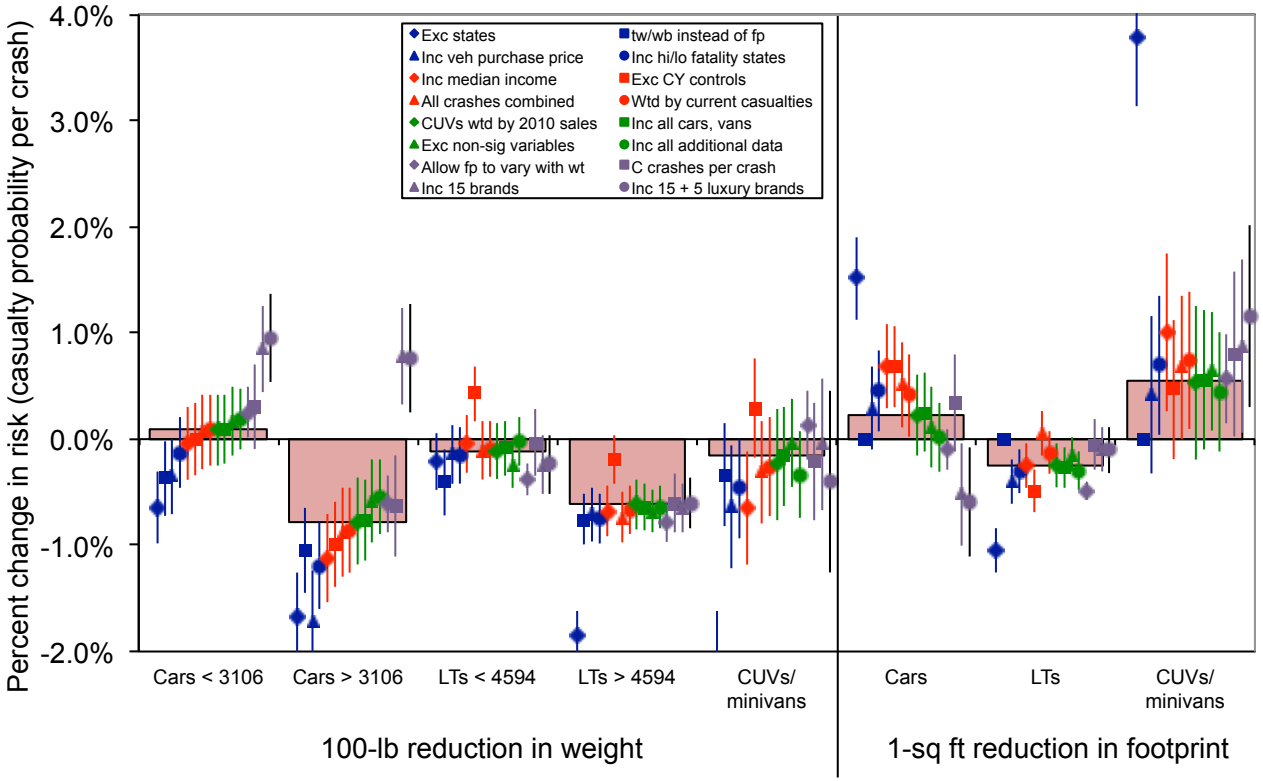
Results of alternative regression models

- Effect of mass reduction on crash frequency varies substantially under 18 alternative regression models
  - Estimated effect of mass reduction in lighter-than-average cars ranges from a 1.22% to a 2.38% increase in crash frequency
  - Mass reduction associated with decrease in crash frequency in only one case: including vehicle purchase for heavier-than-average cars



Results of alternative regression models (cont.)

- Effect of mass reduction on risk per crash varies substantially under 16 alternative regression models
  - Estimated effect of mass reduction ranges from a 0.64% decrease to a 0.96% increase in risk in lighter-than-average cars, and a 1.72% decrease to a 0.76% increase in heavier-than-average cars
  - Estimated effect of mass reduction in light trucks is less sensitive to alternative regressions



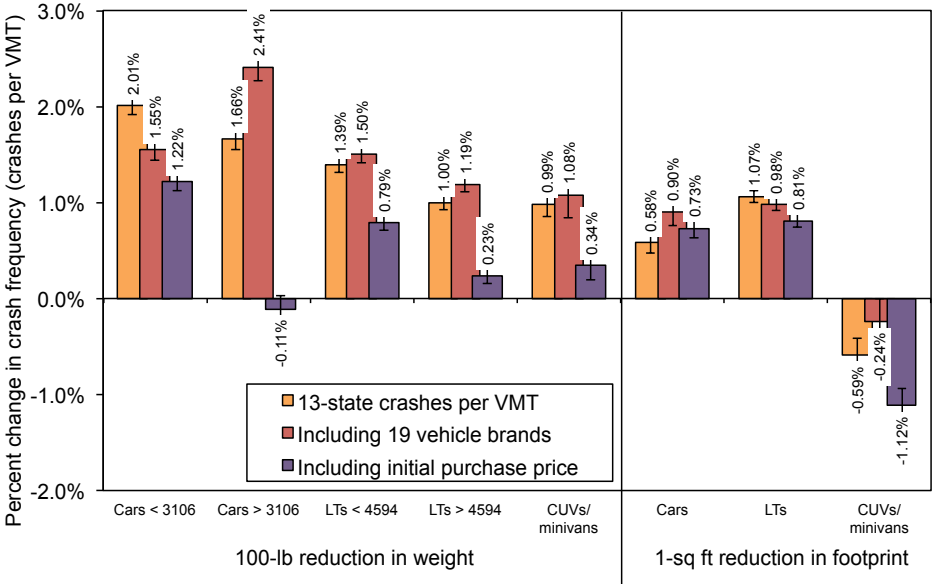
Possible explanations for LBNL Phase 2 results

$$\frac{\text{casualties}}{\text{VMT}} = \frac{\text{crashes}}{\text{VMT}} + \frac{\text{casualties}}{\text{crash}}$$

- Lower-mass vehicles associated with higher crash frequency than higher-mass vehicles
  - Lighter models have worse braking/handling than heavier models?
  - Lighter models have riskier drivers?
  - Heavier models under-report non-injury crashes?
    - we expect crashes involving inexpensive, lower mass vehicles, owned by under-insured drivers, more likely to be under-reported to police
- Lower-mass vehicles associated with lower risk per crash than higher-mass vehicles
  - If any of above overstate number of non-injury crashes in lighter vehicles, they also understate risk per crash
  - Casualties inaccurately reported in lighter vehicles?
    - nearly 40% of incapacitating injuries reported by first responders were actually rated as minor by medical staff
    - 15% of actual serious/severe/critical injuries were reported by first responders as non-incapacitating
    - analyze by vehicle mass
  - Manufacturers have used clever design to mitigate any safety penalty (in terms of crashworthiness) in lighter vehicles?

Do lighter models have worse braking/handling?

- Two indirect variables account for vehicle differences
  - Including 19 vehicle brands
    - Reduces relationship between mass and crash frequency for lighter cars, but increases it for heavier cars
  - Including vehicle price
    - Reduces relationship between mass and crash frequency, especially for heavier cars



- LBNL analyzed relationship between 13 braking/handling tests conducted by Consumer Reports on 491 vehicles, by 6 vehicle types (no large pickups)
  - sporty cars have best average braking/handling characteristics
  - minivans are slowest, SUVs have worst steering/control, small pickups have worst braking and turning radius
- Relationship between mass and test result (6 types * 13 tests = 78 cases)
  - half have unexpected result (braking/handling increases with increasing mass)
- Relationship between crash frequency and test result
  - more have expected result (braking/handling decreases with increasing crash frequency), esp. one-vehicle non-rollover crash frequency
- Very few of relationships are statistically significant ($R^2 > 0.30$)

Do lighter models have worse braking/handling? (cont)

- Relationship between CR test results and vehicle mass

  Expected (b/h decreases as mass increases)

  Unexpected (b/h increases as mass increases); in almost all cases for cars, but few stat-significant

Test	Sporty cars	Cars	Pickups	SUVs	CUVs	Mini-vans
Steering feel rating	-0.01%	0.00%	0.00%	-0.01%	0.00%	-0.03%
Controllability rating	0.05%	0.01%	0.00%	-0.02%	0.00%	0.00%
Acceleration time, 0 to 30 mph	0.03%	-0.05%	0.00%	0.00%	-0.03%	-0.08%
Acceleration time, 0 to 60 mph	0.04%	-0.22%	-0.04%	-0.03%	-0.11%	-0.26%
Acceleration time, 45 to 60 mph	0.00%	-0.14%	-0.03%	-0.02%	-0.07%	-0.12%
Quarter mile time	0.02%	-0.15%	-0.03%	-0.02%	-0.08%	-0.17%
Quarter-mile speed	0.02%	0.92%	0.21%	0.20%	0.47%	0.78%
Max. avoidance maneuver speed	-0.24%	-0.10%	-0.16%	-0.17%	-0.08%	-0.10%
Avoidance maneuver confidence	0.02%	0.00%	0.00%	-0.03%	-0.01%	-0.05%
Dry braking distance	0.83%	-0.15%	0.94%	0.54%	0.03%	0.28%
Wet braking distance	0.52%	-0.25%	1.34%	0.62%	-0.05%	0.19%
Routine handling rating	-0.01%	0.01%	-0.02%	-0.01%	0.00%	-0.01%
Turning circle radius	0.05%	0.27%	0.26%	0.26%	0.12%	0.03%

- Relationship between CR test results and one-vehicle, non-injury crash frequency

  Expected (b/h decreases as crash frequency increases)

Test	2-door cars	4-door cars	Small pickups	SUVs	CUVs	Mini-vans
Steering feel rating	-15.5	-18.4	10.6	-5.1	-16.8	-16.3
Controllability rating	-15.6	-25.4	7.8	-6.7	-14.1	-74.9
Acceleration time, 0 to 30 mph	-1.9	16.1	194.0	13.4	38.8	9.8
Acceleration time, 0 to 60 mph	-2.4	5.7	49.9	5.1	15.3	17.3
Acceleration time, 45 to 60 mph	-14.5	8.7	35.5	18.7	24.0	37.0
Quarter mile time	-1.3	8.8	55.5	6.1	21.2	25.0
Quarter-mile speed	-0.2	-1.8	-5.6	-0.8	-3.7	-5.9
Max. avoidance maneuver speed	-4.9	-1.5	-1.3	3.3	-2.3	-18.5
Avoidance maneuver confidence	-8.9	-16.4	-64.1	-6.3	-4.0	-34.7
Dry braking distance	0.95	1.22	3.64	0.32	3.62	1.82
Wet braking distance	0.36	0.56	1.94	-0.46	0.81	-0.24
Routine handling rating	-14.1	-20.4	-7.0	-1.7	-33.6	-56.2
Turning circle radius	9.5	1.4	4.3	-1.6	1.2	6.3

Do lighter models have worse braking/handling? (cont)

Add CR test results to car regression for frequency of all crashes

- little effect on crash frequency for lighter cars (UNDRWT00)
- reduces crash frequency for heavier cars (OVERWT00)
- sign on CR tests not in expected direction

Variable	NHTSA preferred model (crashes per VMT)	1. Using only vehicles with CR test results	2. Including MANEUVER (max speed on avoidance maneuver test)	3. Including ACC45TO60 (secods to accelerate from 45 to 60 mph)	4. Including DRYBRAKE (stopping distinace in feet on dry surface	5. Including MANEUVER, ACC45TO60, and DRYBRAKE
UNDRWT00	2.00%*	1.97%*	1.87%*	2.11%*	1.96%*	2.04%*
OVERWT00	1.50%*	1.40%*	1.27%*	1.33%*	1.35%*	1.25%*
FOOTPRNT	0.64%*	0.72%*	0.70%*	0.85%*	0.73%*	0.83%*
MANEUVER	—	—	0.53%*	—	—	0.27%*
ACC45TO60	—	—	—	-1.27%*	—	-1.13%*
DRYBRAKE	—	—	—	—	-0.07%*	-0.03%*

* statistically significant at the 95% level.

Add CR test results to car regression for frequency of one-vehicle non-injury crashes only

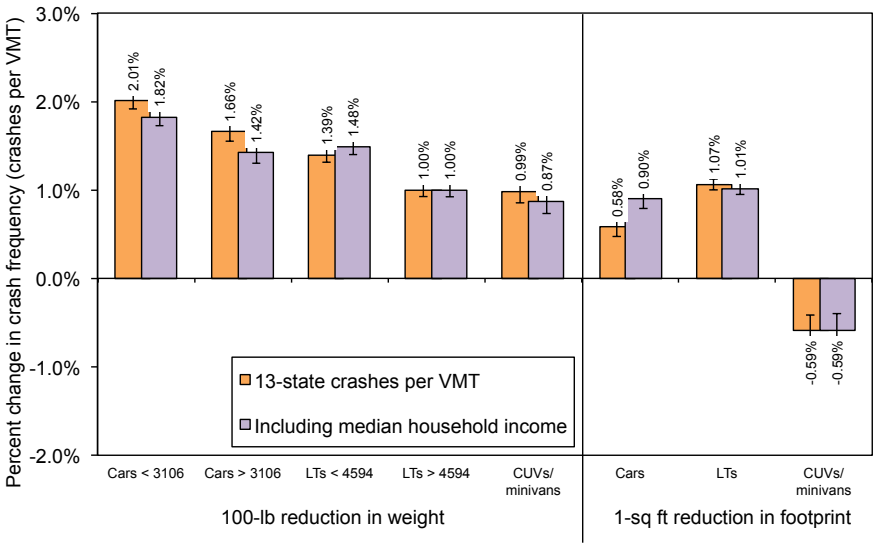
- little effect on crash frequency for lighter cars (UNDRWT00)
- substantially reduces crash frequency for heavier cars (OVERWT00)
- sign on CR tests in expected direction

Variable	NHTSA preferred model (crashes per VMT)	1. Using only vehicles with CR test results	2. Including MANEUVER (max speed on avoidance maneuver test)	3. Including ACC45TO60 (secods to accelerate from 45 to 60 mph)	4. Including DRYBRAKE (stopping distinace in feet on dry surface	5. Including MANEUVER, ACC45TO60, and DRYBRAKE
UNDRWT00	1.24%*	1.33%*	0.86%*	1.66%*	1.28%*	1.25%*
OVERWT00	-0.10%	-0.54%*	-1.21%*	-0.73%*	-0.83%*	-1.27%*
FOOTPRNT	2.45%*	2.75%*	2.68%*	3.05%*	2.81%*	2.96%*
MANEUVER	—	—	-2.65%*	—	—	-1.64%*
ACC45TO60	—	—	—	3.04%*	—	2.20%*
DRYBRAKE	—	—	—	—	0.43%*	0.27%*

* statistically significant at the 95% level.

Do lighter models have riskier drivers?

- Adding average median household income by vehicle model (from CA DMV data)
  - little change in estimated effect of mass or footprint reduction on crash frequency

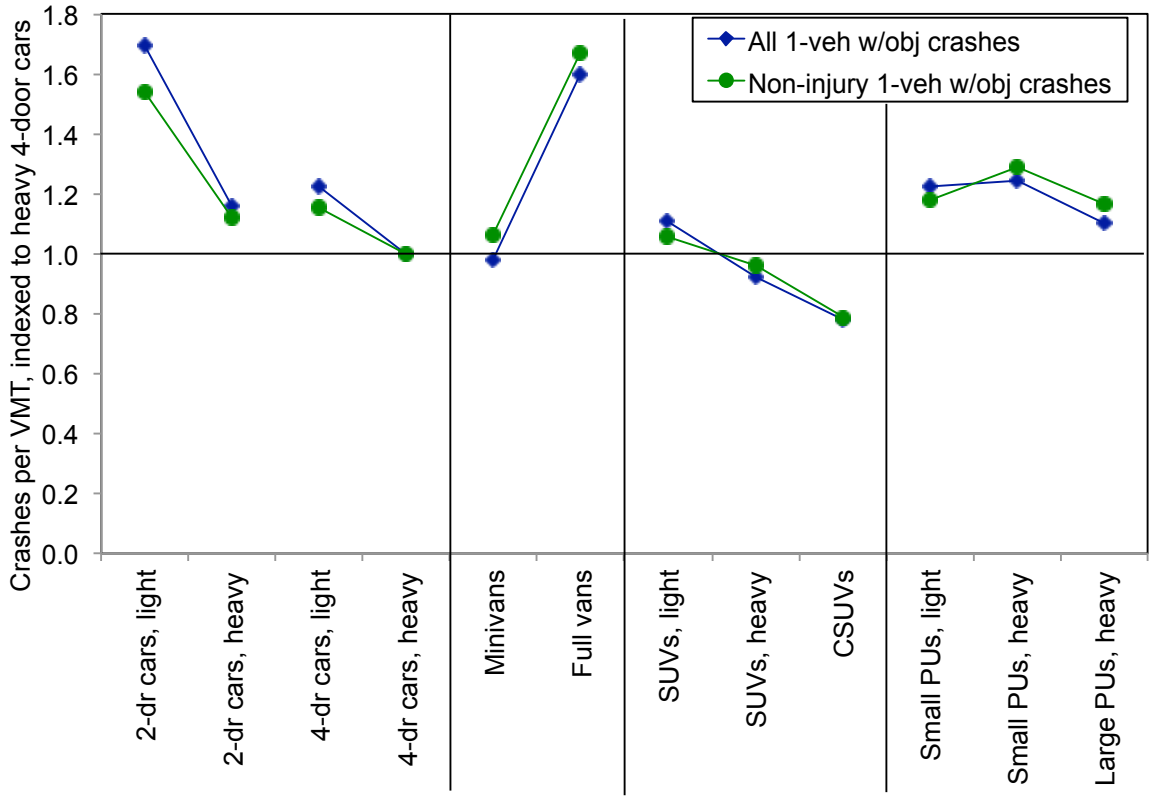


- Identify risky drivers in state crash data by
  - seatbelt use
  - drug/alcohol use

- Analyze the few states with
  - info on driving record
  - driver zip code (to obtain median household income)

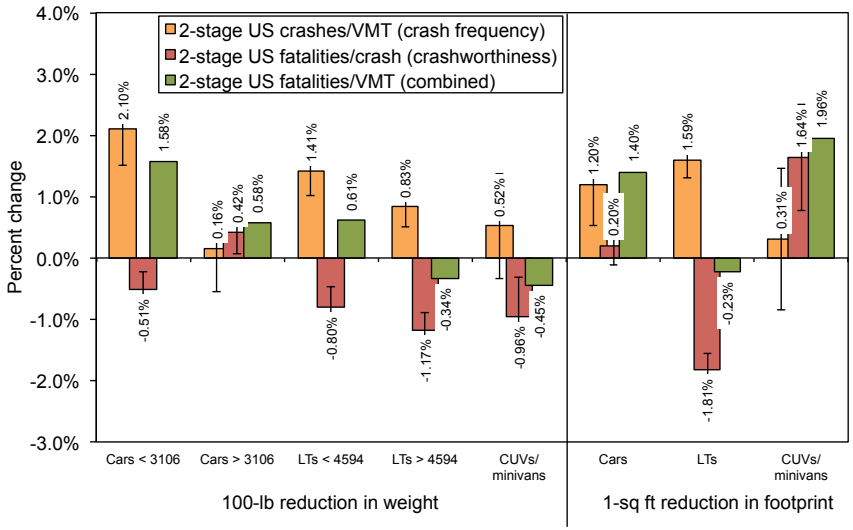
Are non-injury crashes under-reported for heavier vehicles?

- Non-injury one-vehicle crashes may be under-reported to police
- Greater under-reporting of these crashes involving heavier vehicles may understate their crash frequency
- Compare all vs. non-injury one-vehicle crash frequency per VMT by vehicle type
  - Non-injury one-vehicle crashes are "under-reported" for lighter cars and light trucks
  - Non-injury one-vehicle crashes are "over-reported" for heavier pickups



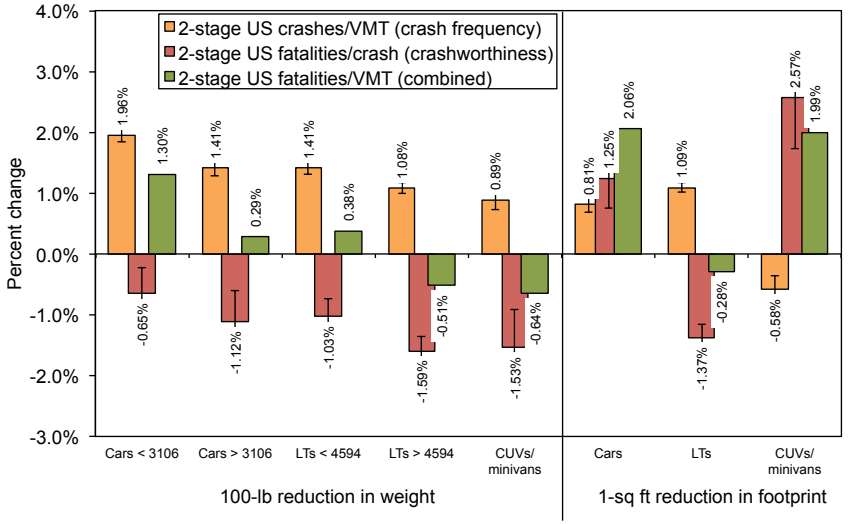
Conclusions from LBNL review of DRI 2013

- 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 Phase 2 casualty risk analysis: mass reduction increases crash frequency, but reduces risk per crash



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 (belt use, alcohol/drug use if available) 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 associated with an increase in crash frequency, but a decrease in risk per crash
  - Possible causes are worse braking/handling, or riskier drivers, in lighter vehicles; or that manufacturers have mitigated safety penalty in lighter vehicles

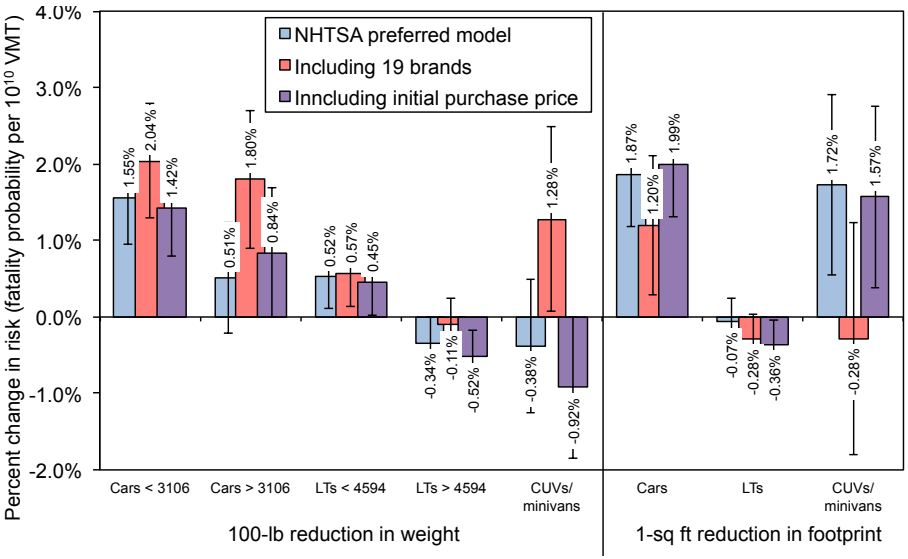
Back-Up Slides

Alternative regression models in LBNL Phase 1 (cont.)

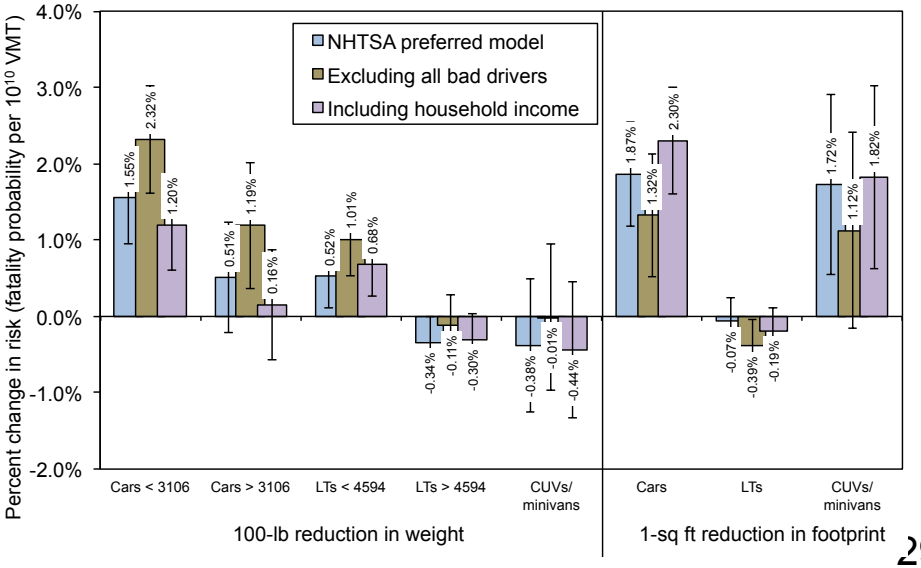
- No correlation between residual risk and mass by vehicle model; differences in residual risk by model due to
  - Differences in vehicle design (other than mass, footprint, safety features)?
  - Differences in driver behavior (other than age and gender)?
- Two measures of vehicle design
  - 19 vehicle 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)
- Allowing footprint to vary with mass (and vice versa)
- 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

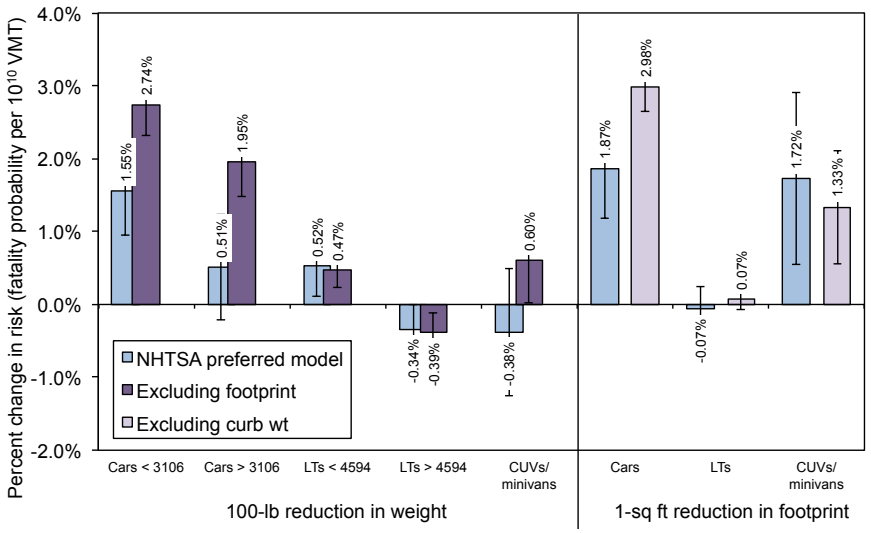


- Alternative models accounting for driver differences
  - Excluding crashes with alcohol/ drug use and poor driving
    - Increases detrimental effect of mass reduction in all five vehicle types
    - Reduces detrimental effect of footprint reduction in all three vehicle types
  - Including household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

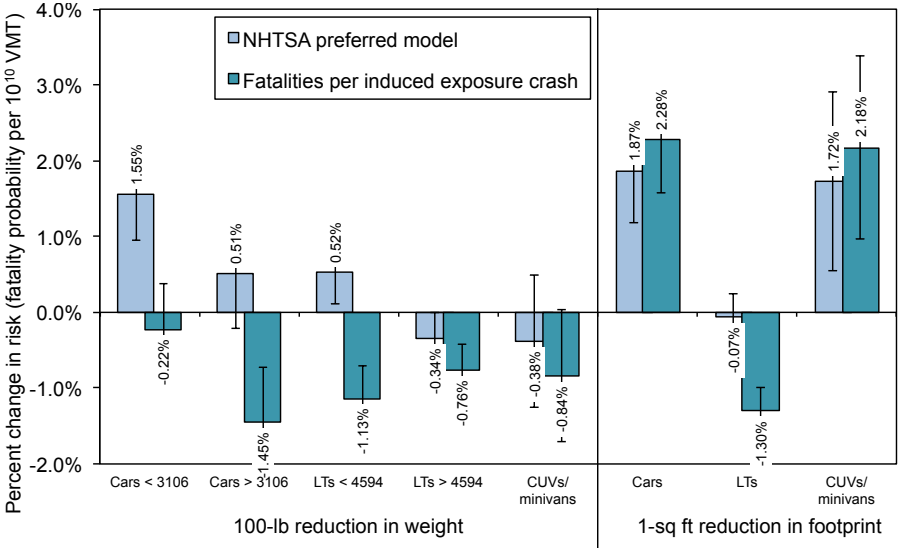


Alternative regression models in LBNL Phase 1

- 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

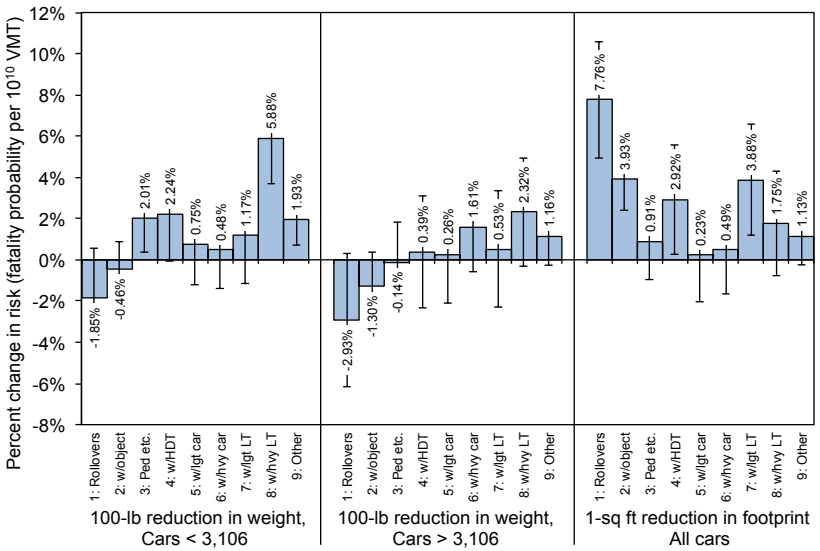


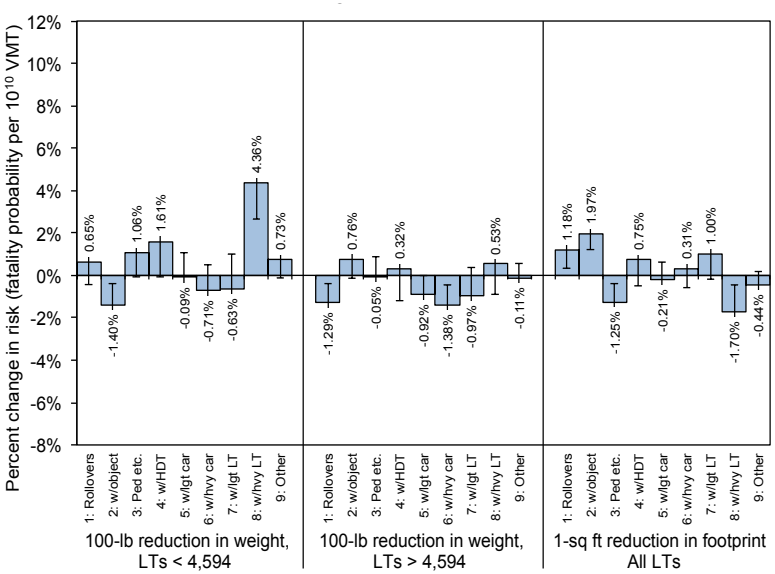
- Alternative measure of risk
  - US fatalities per induced exposure crash (crashworthiness/compatibility)
    - Mass reduction in all five vehicle types associated with reduction in fatality risk per crash

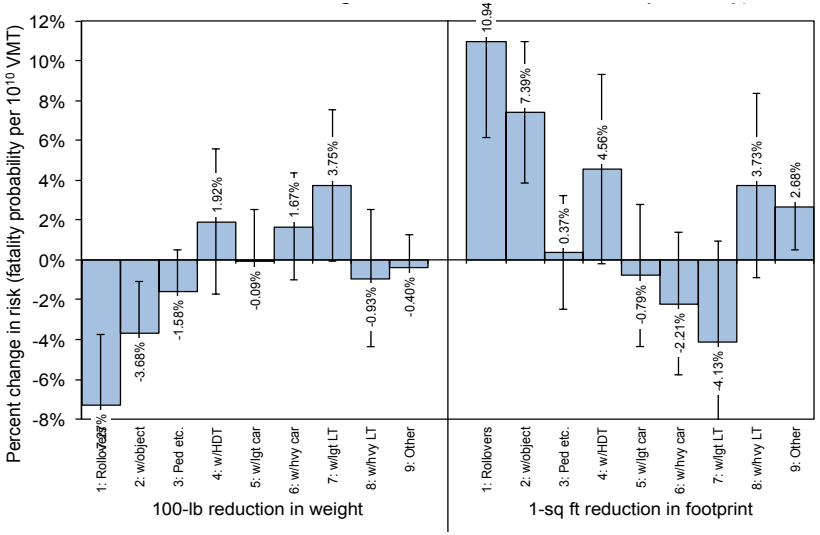


Estimated US fatality risk by crash type

- 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

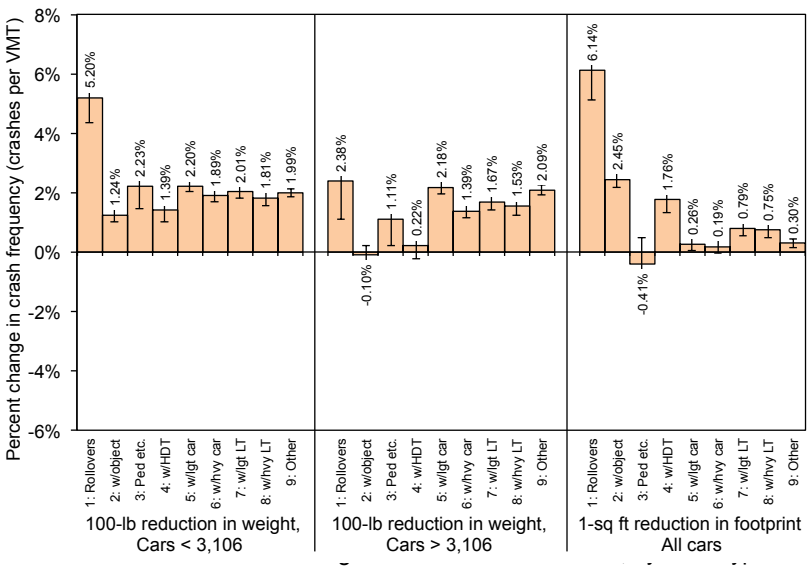


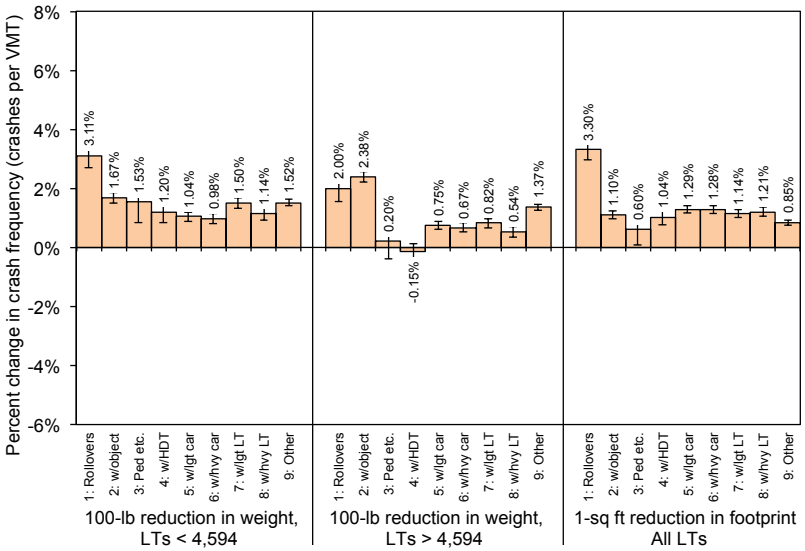


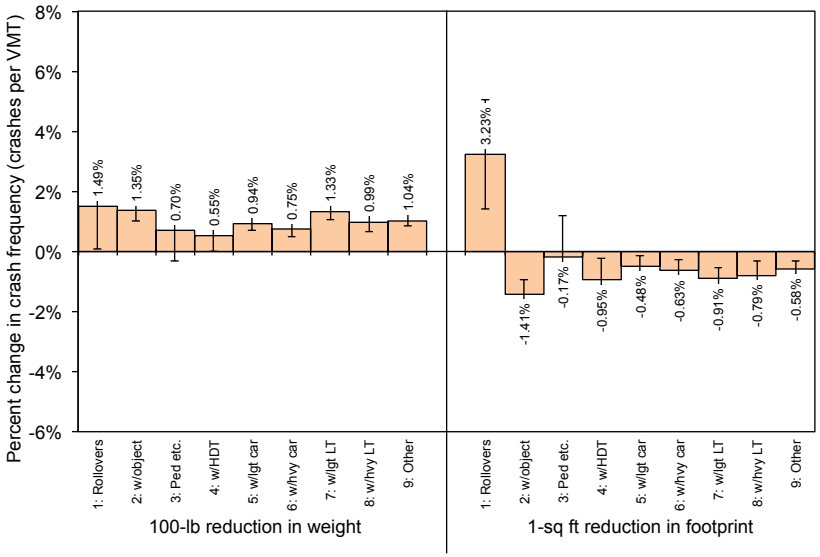


Estimated crash frequency by crash type

- Mass reduction associated with increase in crash frequency in nearly all crash types
- Highest increase in rollover crashes involving lighter-than-average cars

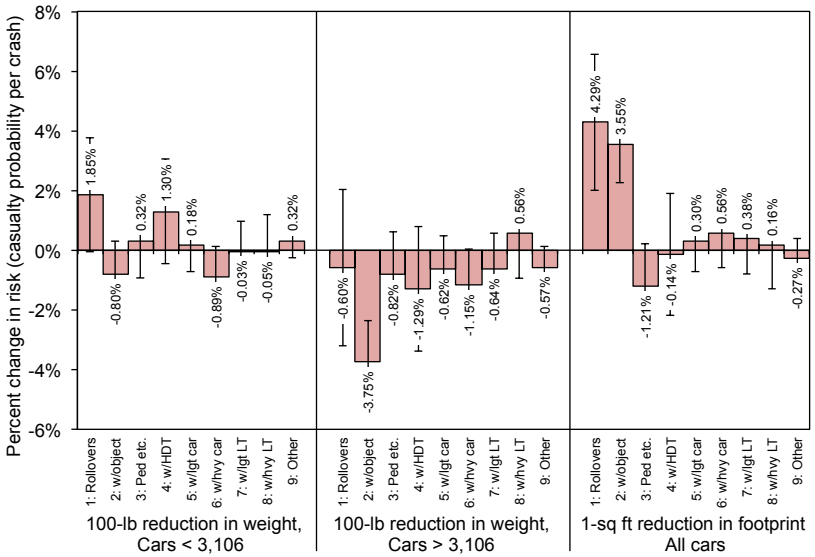


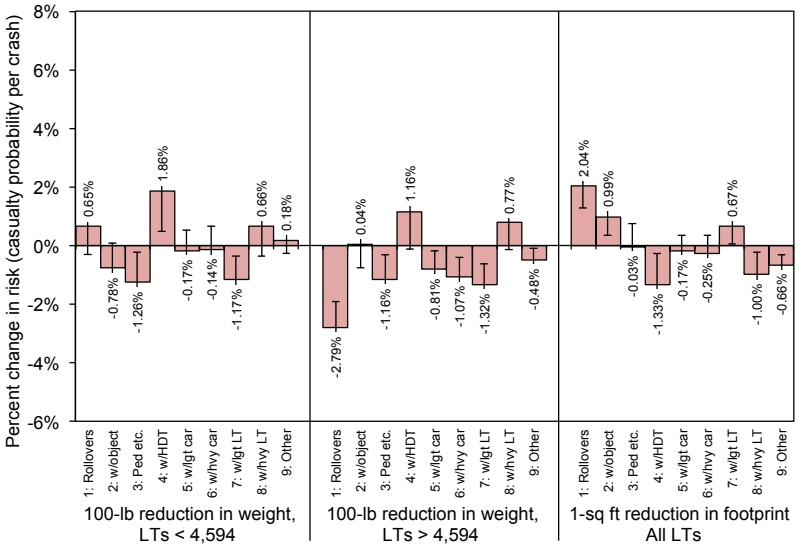


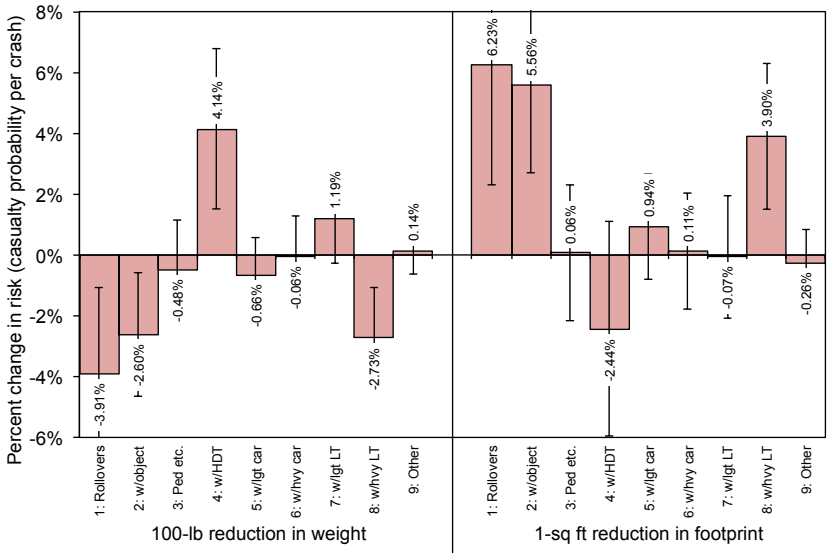


Estimated casualty risk per crash by crash type

- Mass reduction associated with decrease in casualties per crash in nearly all crash types, especially heavier-than-average cars with stationary objects, and heavier-than-average light trucks and CUVs/ minivans in rollovers
- Mass reduction associated with increase in risk per crash in lighter-than-average cars in rollovers, and all vehicle types in crashes with heavy-duty trucks

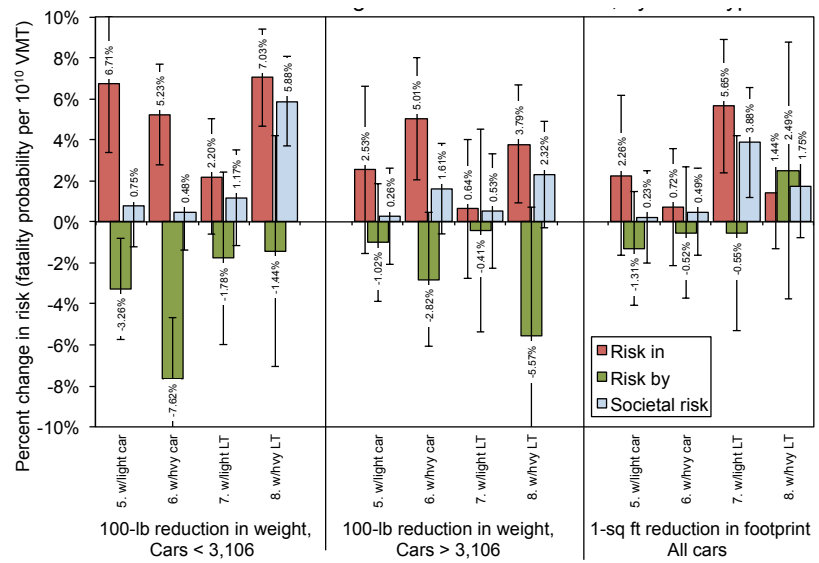


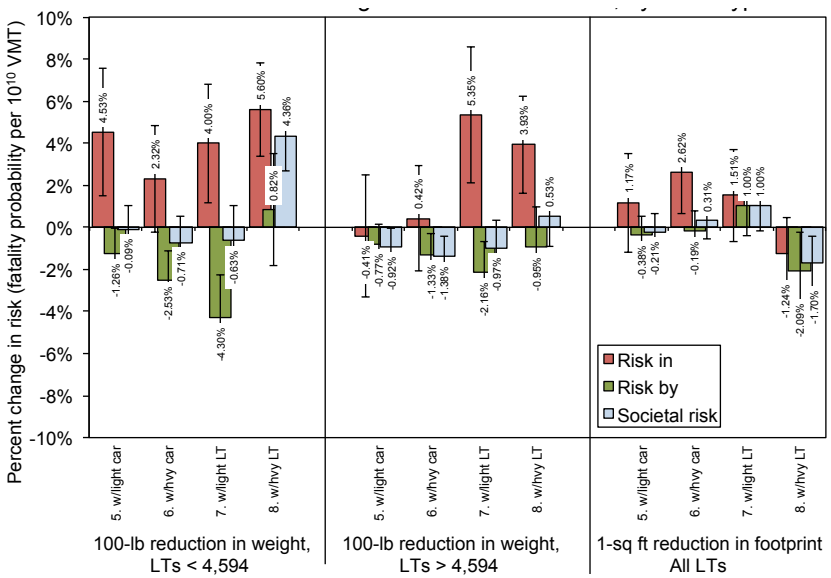


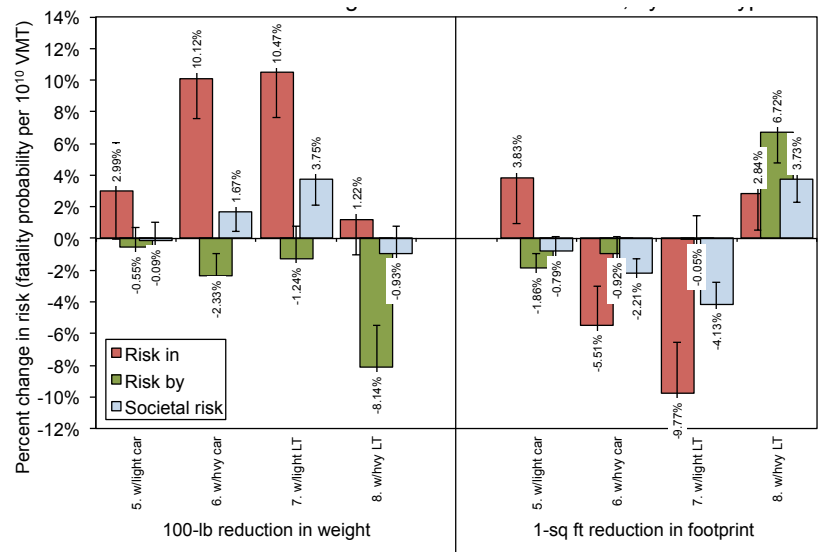


Risk in and risk by estimates by crash type

- 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

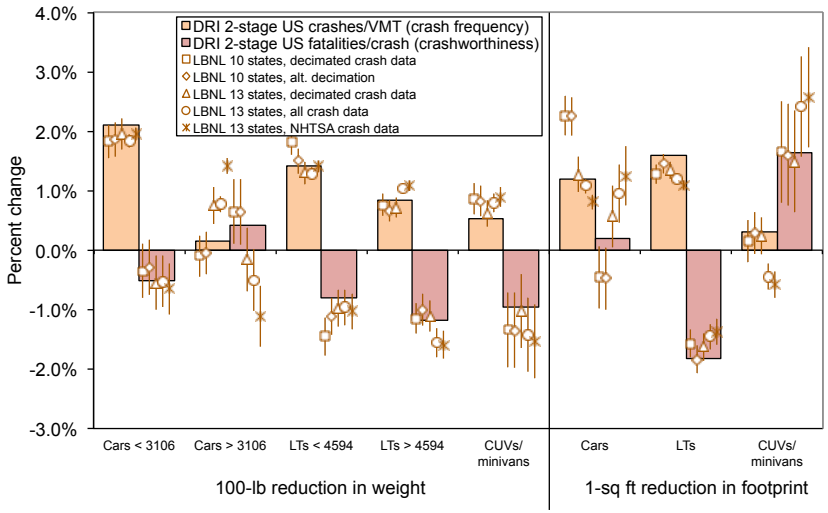






LBNL 2-stage alternative regressions

- LBNL replicated DRI method, and examined 5 alternate models
  - 10 states, decimated (sampled) crash data
  - 10 states, alternative decimated crash data
  - 13 states, decimated (sampled) crash data
  - 13 states, all crash data
  - 13 states, NHTSA method (duplicate missing state/CY data, include only where reported MY matches VIN)
- Including 13 states gives expected sign for crash frequency and crashworthiness for heavier cars
- LBNL alternatives tend to increase effect of mass reduction on crash frequency and crashworthiness for light trucks and CUVs/minivans



Multi-collinearity between vehicle mass and footprint

- Mass has historically been correlated with footprint
  - Pearson correlation coefficient (r) ranges from below 0.70 for minivans and large pickups to 0.90 for 4-door cars and SUVs
- No consensus on what level of variance inflation factor (VIF) constitutes a problem
  - Allison: “begins to get concerned” if VIF > 2.5
  - Menard: “cause for concern” if VIF > 5.0; “serious collinearity problem” if VIF > 10
  - O’Brien: “VIF > 40 does not by itself discount results of regression”
- VIF for curb weight from 1.5 to 6.8 depending on vehicle type
- NHTSA ran separate regressions for footprint deciles
  - What is relationship between risk and mass for vehicles with similar footprint?

Multi-collinearity between vehicle mass and footprint (cont.)

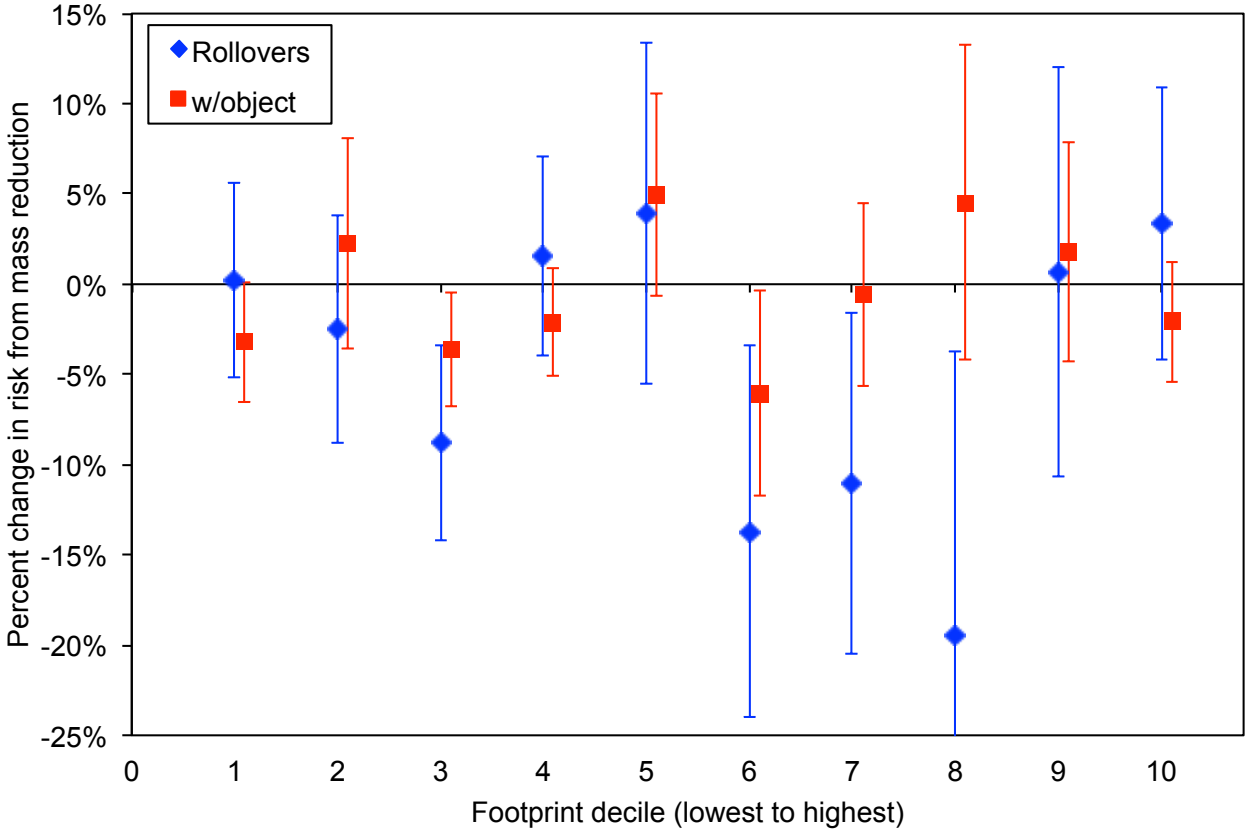
- 27 crash and vehicle combinations:
  - in 12, risk increases with decreasing mass in a majority of footprint deciles
  - in 5, risk decreases with decreasing mass in a majority of footprint deciles
  - estimates of increasing or decreasing risk as mass decreases are statistically-significant in very few of the deciles

Crash type	Cars Number of deciles with		Light trucks Number of deciles with		CUVs/Minivans Number of deciles with	
	increasing risk	decreasing risk	increasing risk	decreasing risk	increasing risk	decreasing risk
1: Rollovers	5 (0)	5 (4)	6 (3)	4 (2)	4 (0)	6 (2)
2: w/object	4 (0)	6 (2)	5 (0)	5 (0)	5 (0)	5 (1)
3: w/ped etc.	7 (2)	3 (2)	5 (1)	5 (1)	3 (0)	7 (0)
4: w/HDT	7 (0)	3 (0)	7 (2)	3 (0)	6 (1)	4 (0)
5: w/lgt car	5 (0)	5 (0)	3 (1)	7 (4)	5 (1)	5 (0)
6: w/hvy car	5 (1)	5 (0)	3 (0)	7 (3)	8 (3)	2 (1)
7: w/lgt LT	5 (1)	5 (1)	6 (0)	4 (0)	7 (0)	3 (0)
8: w/hvy LT	7 (2)	3 (0)	9 (2)	1 (0)	5 (0)	5 (2)
9: Other	6 (1)	4 (1)	5 (1)	5 (1)	6 (1)	4 (1)

Numbers in parentheses are the number of deciles whose estimates are statistically significant.

Multi-collinearity between vehicle mass and footprint (cont.)

- Example: cars
  - In rollovers (◆), 5 deciles (0 significant) show increasing risk, while 5 (4 significant) show decreasing risk, with decreased mass
  - In crashes with an object (■), 4 deciles (0 significant) show increasing risk, while 6 (2 significant) show decreasing risk, with decreased mass



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.
  - Wenzel, Tom. 2013. "Relationships between Vehicle Mass, Footprint and Societal Risk." Presented at NHTSA Mass-Size-Safety Workshop, Washington DC, May 13-14.
  - Wenzel, Tom. 2013. "Relationships between Vehicle Mass, Footprint and Societal Risk." Presented at DOE 2013 Annual Merit Review, Washington DC, May 15.
- 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." Accepted for publication in *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 *Traffic Injury Prevention*.