Fleet Fatality Risk Sensitivity to Vehicle Mass/Size Change

in Vehicle-to-Vehicle Crashes

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Combined Empirical and Theoretical Modeling

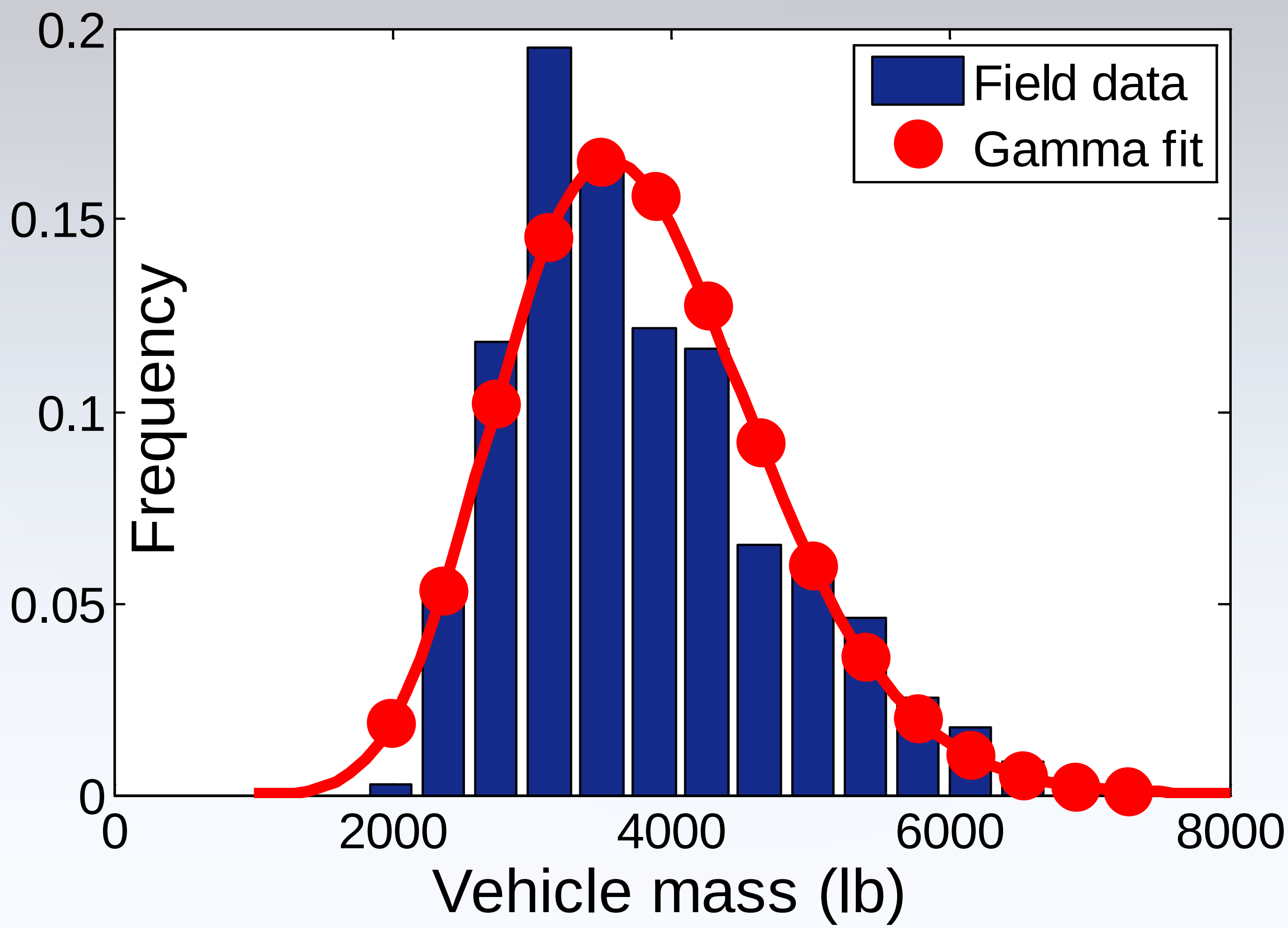
Parameterized Accident and other Data to form basis for a set of equations.

Include the laws of physics.

–A FLEET MODEL IS CREATED

Different from building the model from the crashing of computational cars such as in FEA

Input



Mass distribution data (5,262 vehicles) from F-F crashes from FARS [Kahane 2012]

The modeling goal: Fatality risk

Fatality Risk = f (m, other vehicle parameters; Driver functions; Road conditions)

Difficult task – data availability, data variability, numerical methods, complexity → ***uncertainty;***

Background -- 2

Evans, et. al. Mass; Risk ratio(92)

Joksch Mass (93)

Kahane Fatality Rate multi-regression models ('97, '03, '12)

van Auken et. al. Fatality Rate multi-regression models ('02 - '12)

Padamanaban Fatality Rate multi-regression models (03-09)

Shi and Nusholtz Fatality Rate multi-regression models (13)

Model Development

(1) Fatality Risk Empirical Model (EM1)

$$r = \left(\frac{v}{v_{0p}}\right)^{a}$$

α	3.88 +- 0.19
v_{0p} (mph)	70.6

[Joksch 1993]

(2) Fatality Risk Ratio Empirical Models-vehicle-vehicle crashes (EM2);

$$\frac{r_1}{r_2} = \left(\frac{m_2}{m_1}\right)^{\beta}$$

β	3.36; 3.58; 3.73

[Evans 1992, etc.]

$$\ln\frac{r_1}{r_2} = -3.83\ln\frac{m_1}{m_2} - 0.31D_{VTYPtruck} - 0.33D_{VTYPsuv} - 0.34D_{VTYPcuv} - 0.37D_{ESC} - 1.20D_{REST\_USE} + 0.05D_{A14-30} + 0.03D_{A38-60} + 0.05D_{A60-90}$$

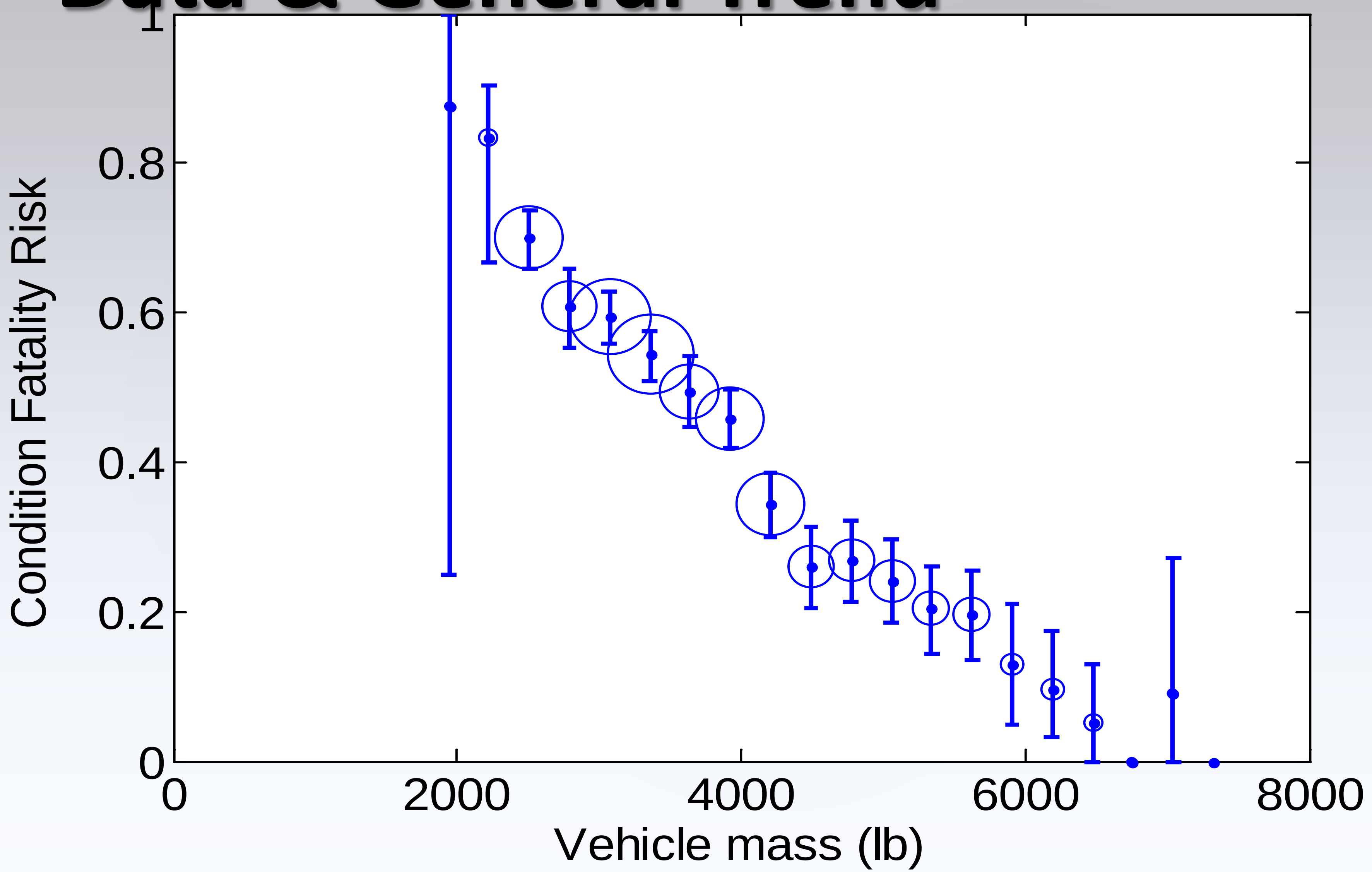
[Shi & Nusholtz 2013]

(3) *r = f(m; VTYP, age, rest use; ....)* ?

Data & General Trend

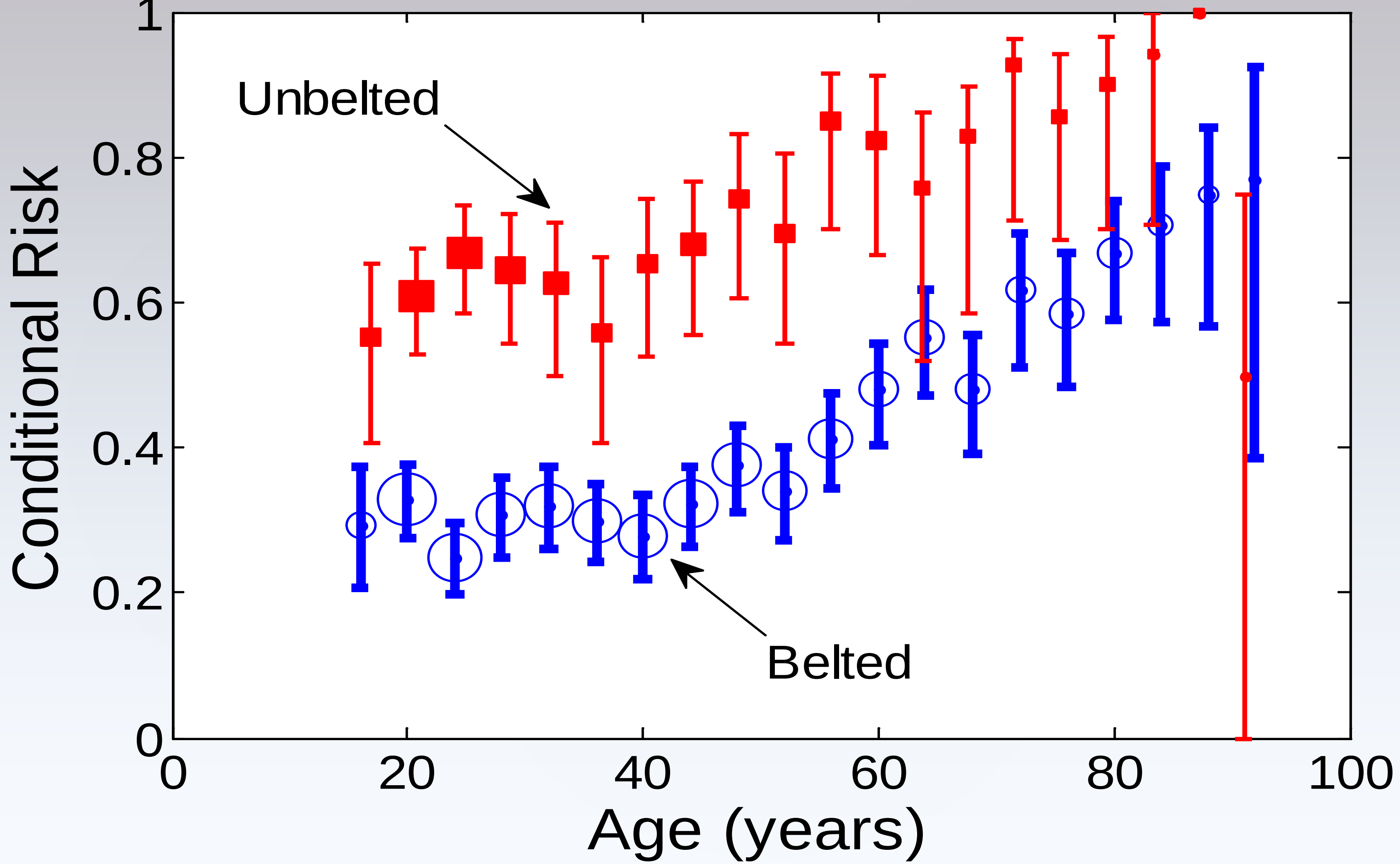
- Data
  - **From Kahane [2012]: FARS MY 2000-2007, CY 2002-2008.**
  - **Supplemented with: Impact direction; Belt…**
  - **Vehicle-Vehicle cases only**
  - **Separately front-front cases**
  - **Separately front-left cases**
- General trend & Multi-regression

Data & General Trend



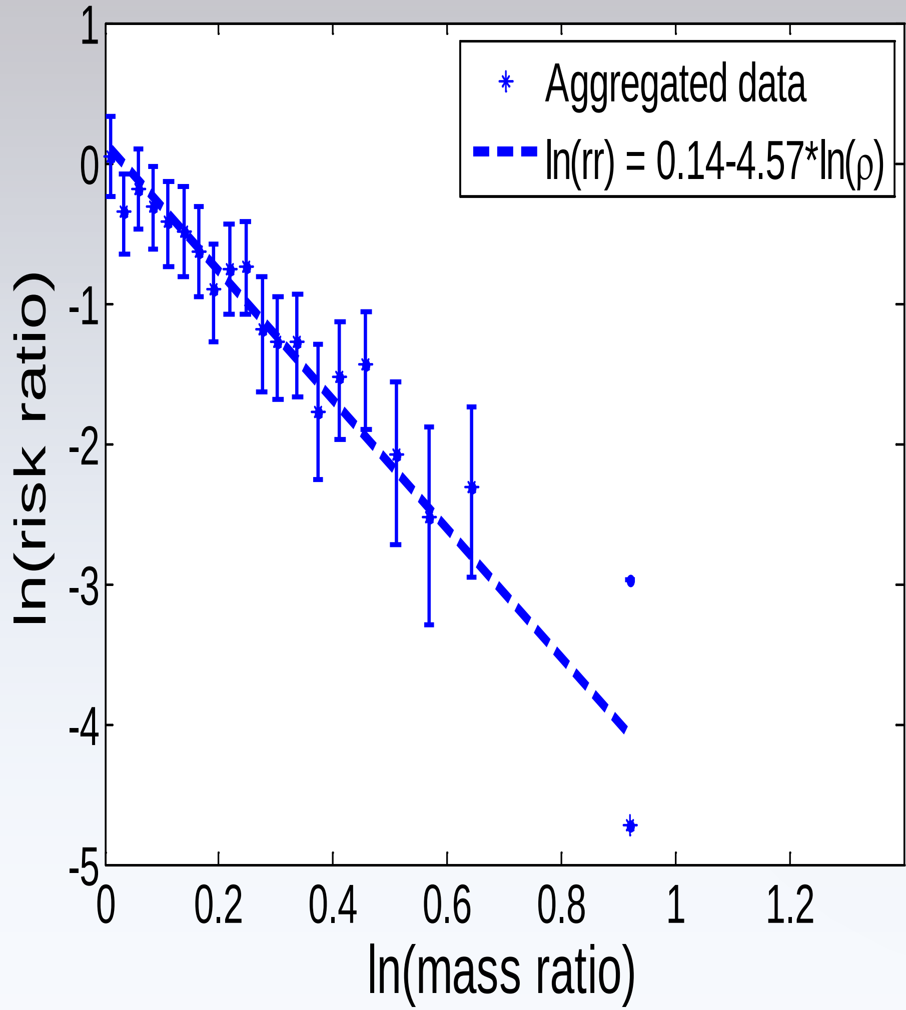
Front-front crashes. Conditional fatality risk.

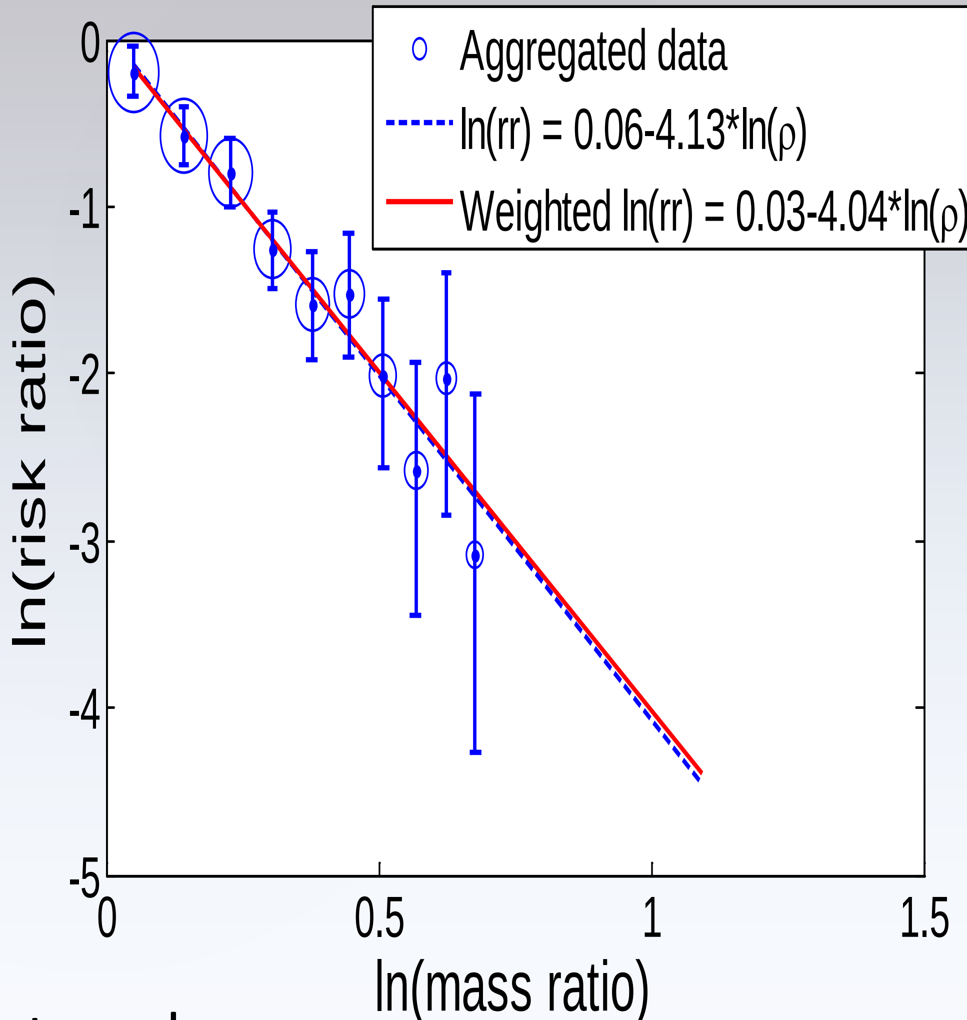
Data & General Trend



Front-front crashes. Conditional fatality risk.

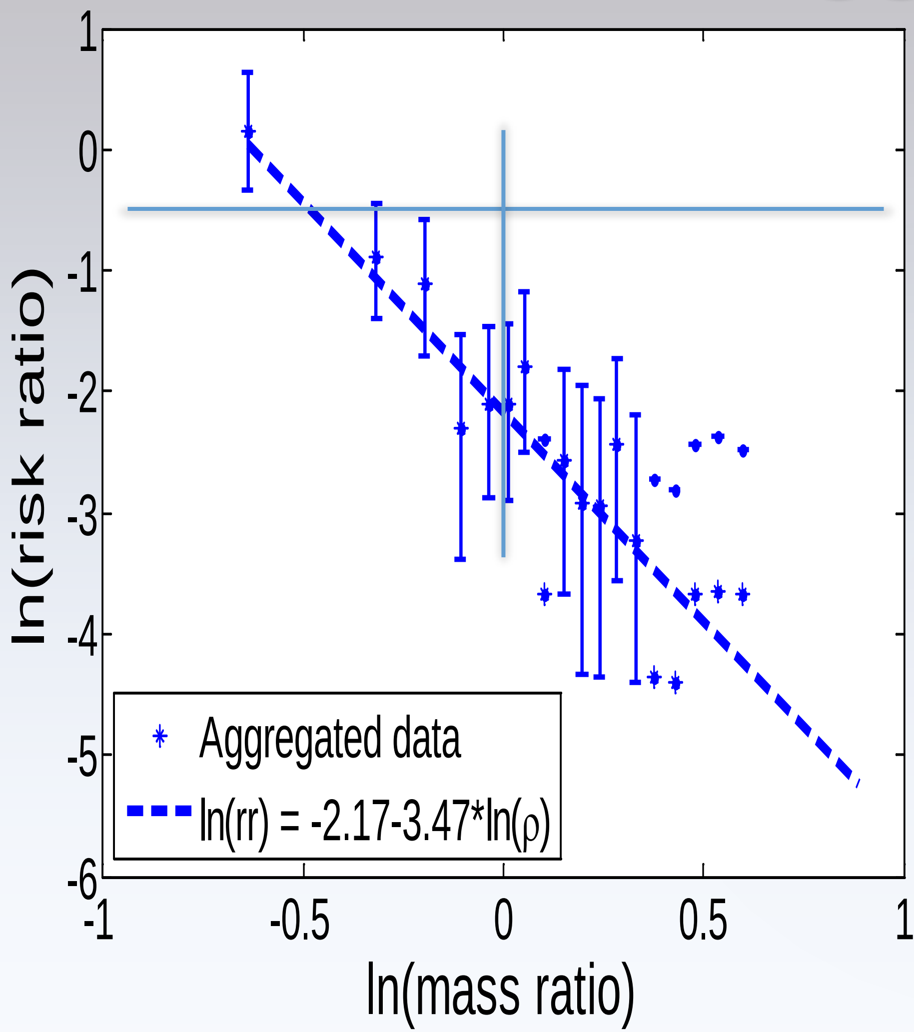
Risk Ratio -- aggregated

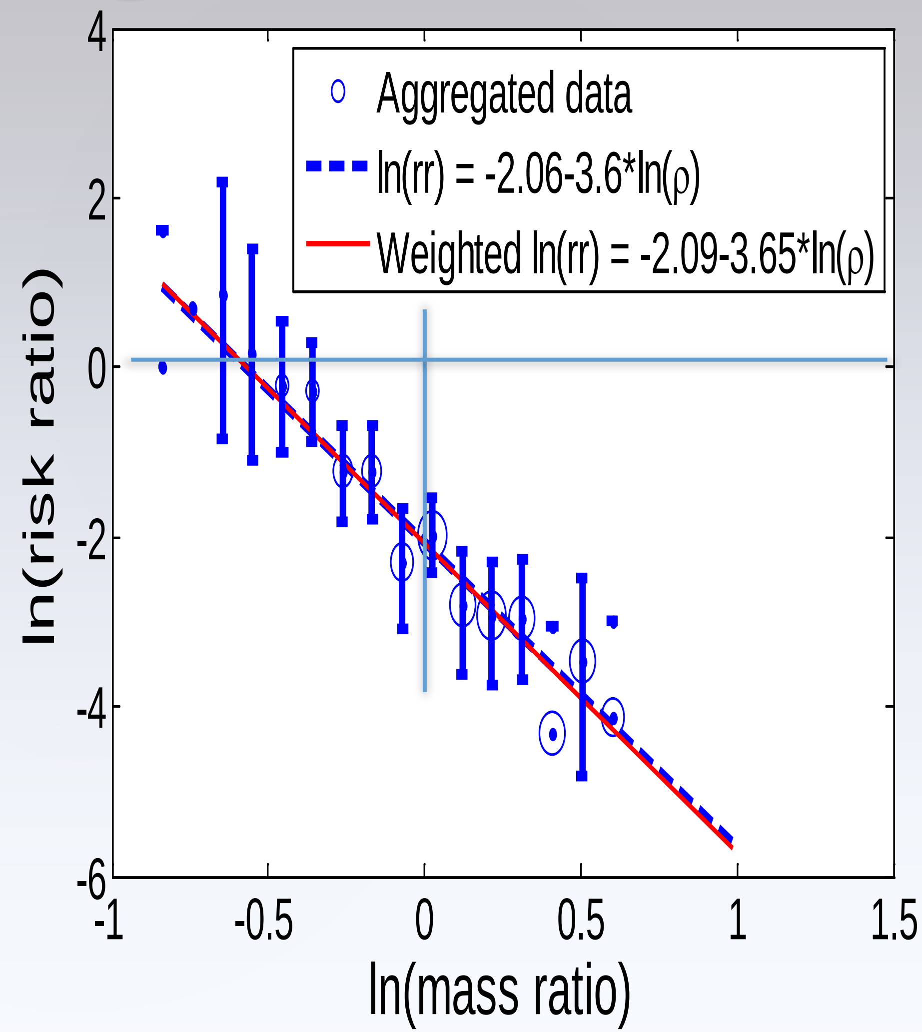




Front-front crashes

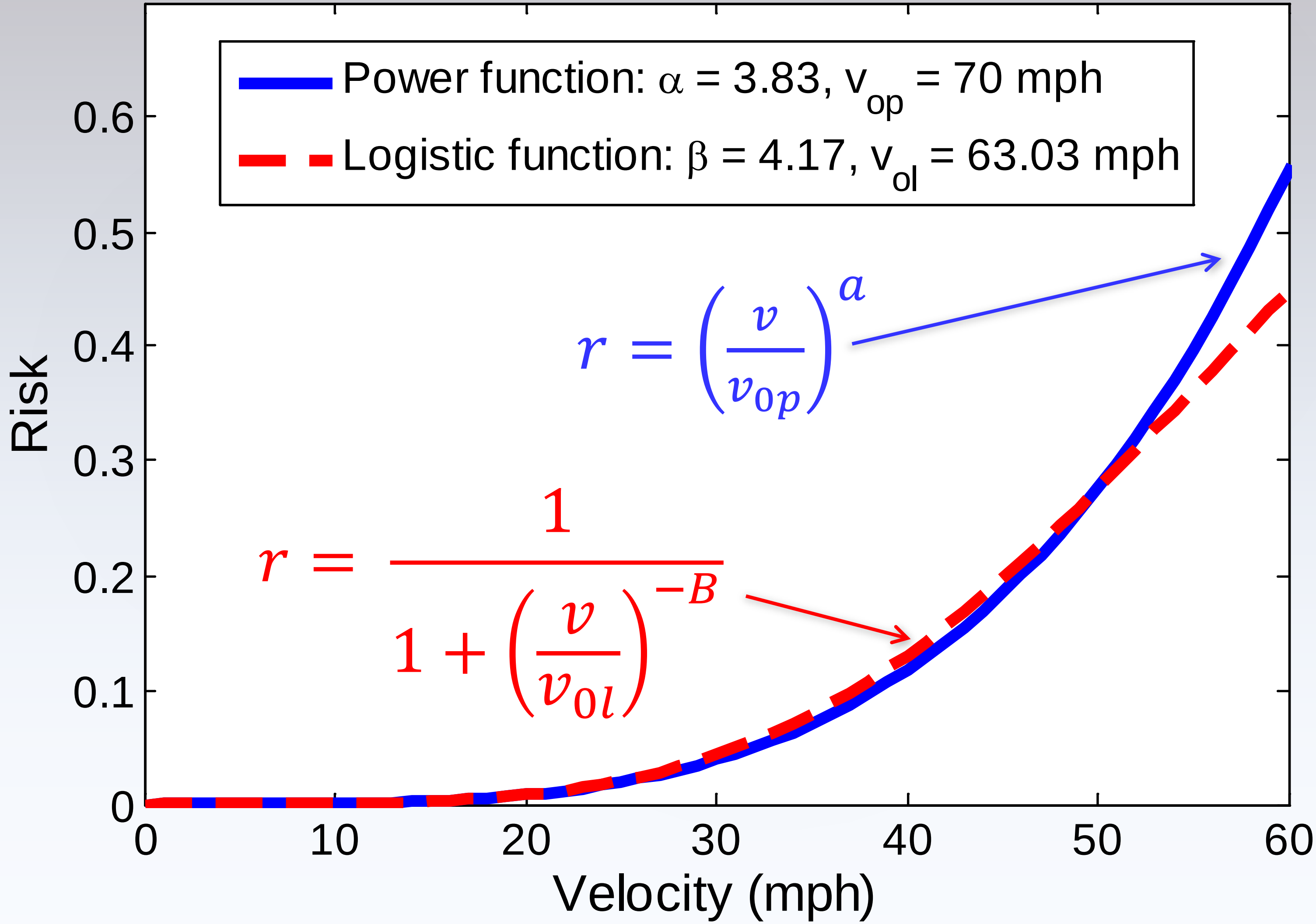
Risk Ratio -- aggregated





Front-Left crashes

Discussion: Uncertainty with Risk Function



Multi Regression of Risk Ratio

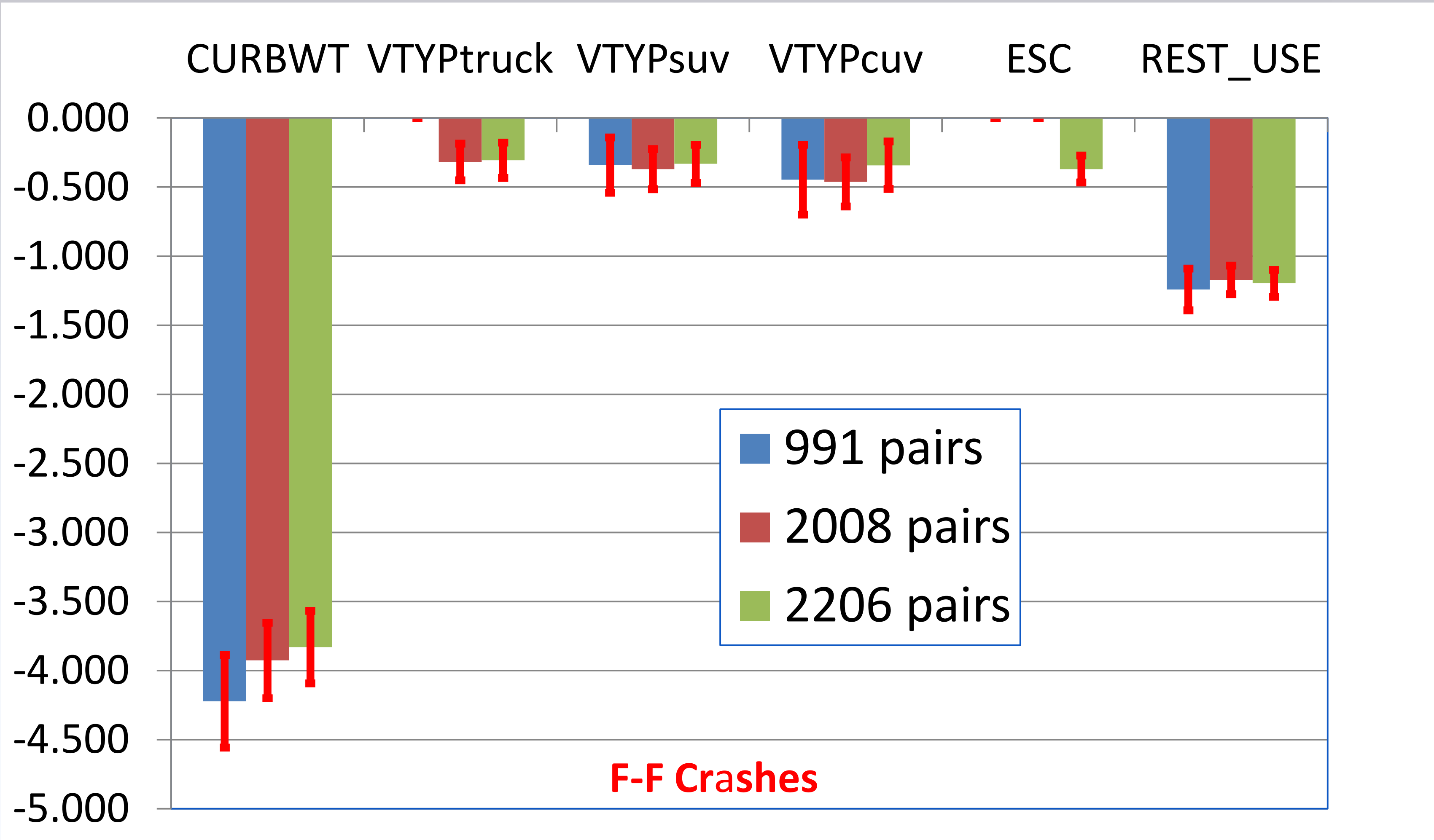
$$ln\frac{r_1}{r_2} = \beta_0 + \sum \beta_i(x_{i1} - x_{i2});\ \ Log - linear$$

$$f = \frac{r_1}{r_1 + r_2}$$

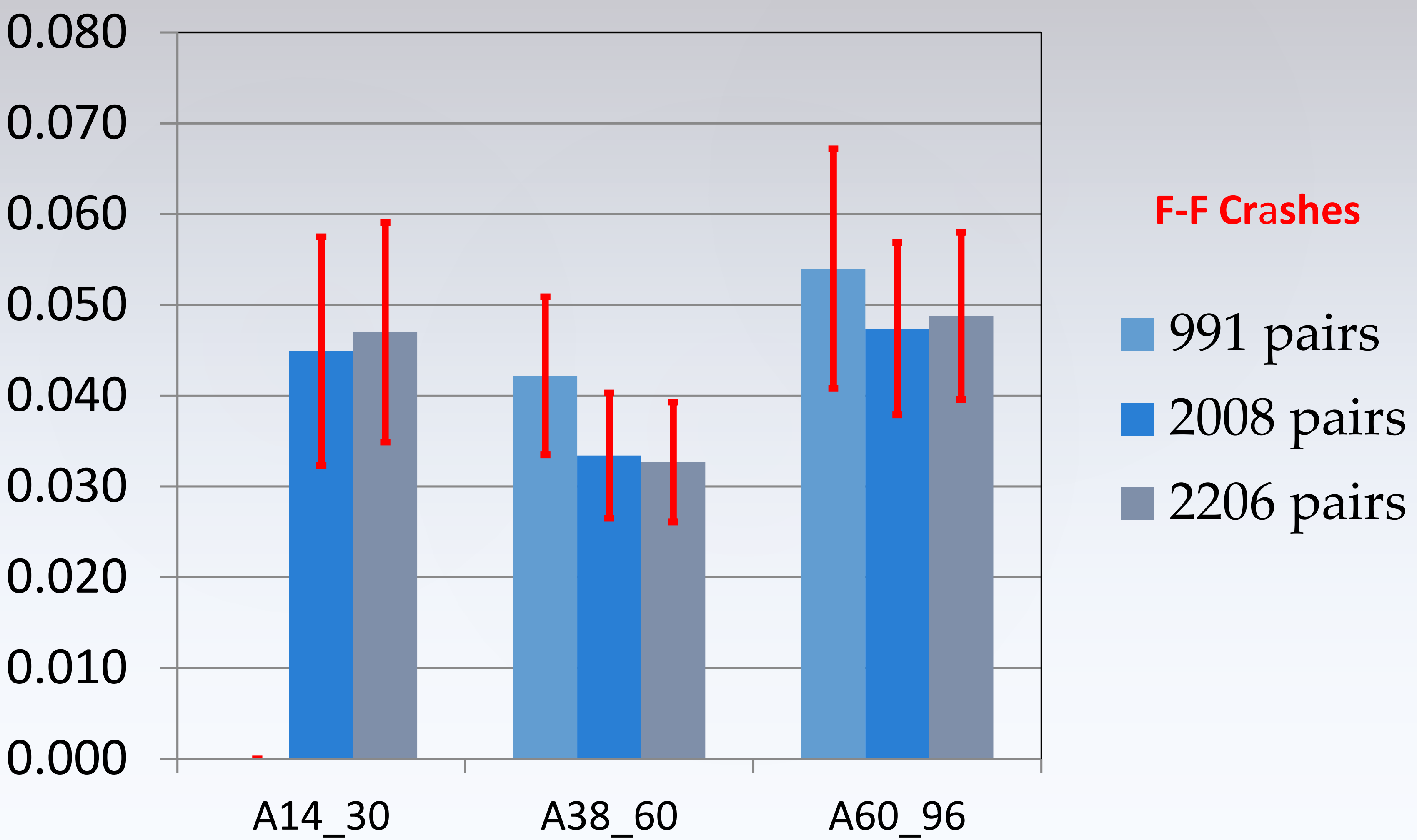
Vehicle 1	Vehicle 2	binary outcome of f
1	0	1
0	1	0
1	1	0 & 1

$$ln\frac{f}{1-f} = \beta_0 + \sum \beta_i(x_{i1} - x_{i2}); Logoistic$$

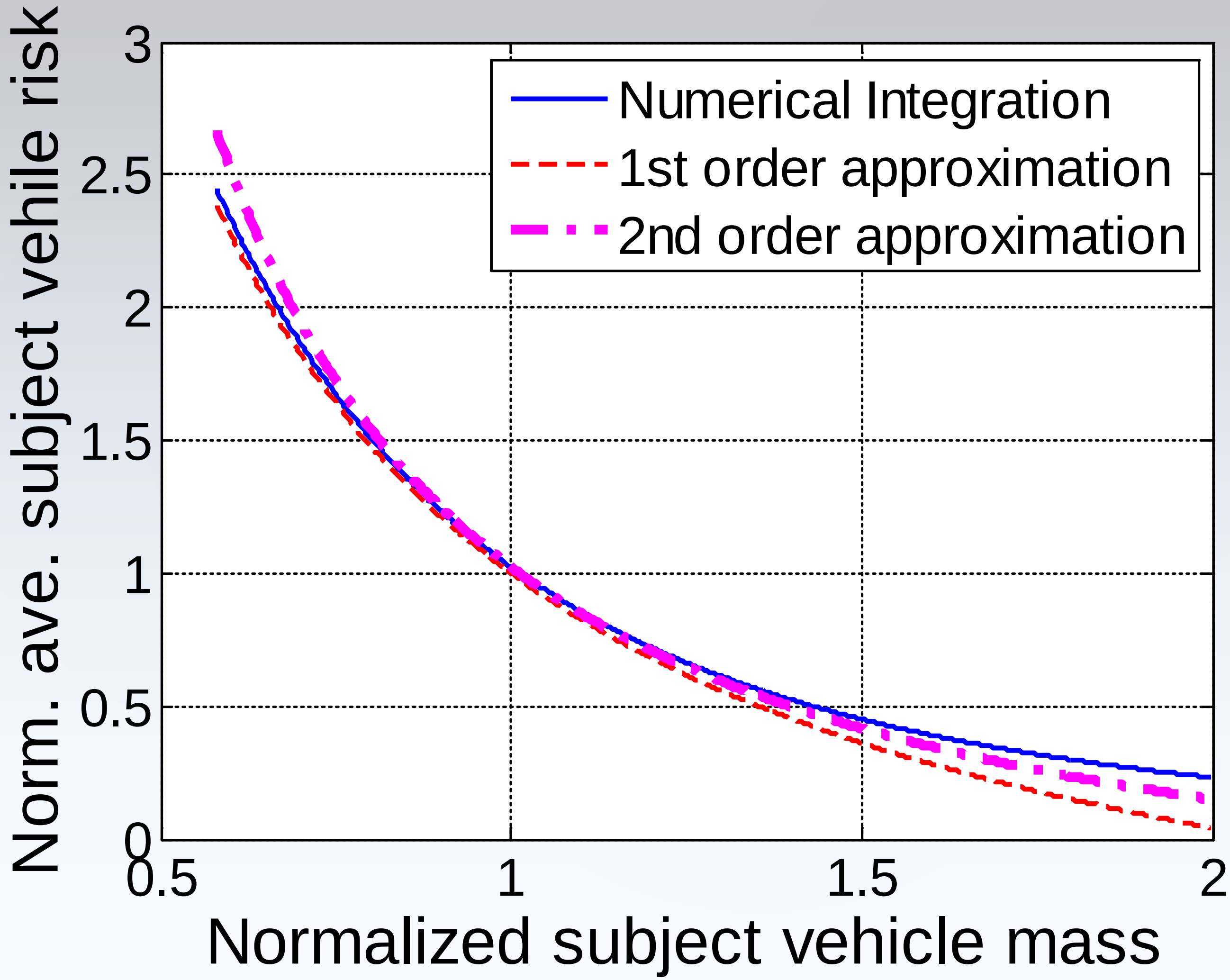
Stability of Regression Result



Stability of Regression Result

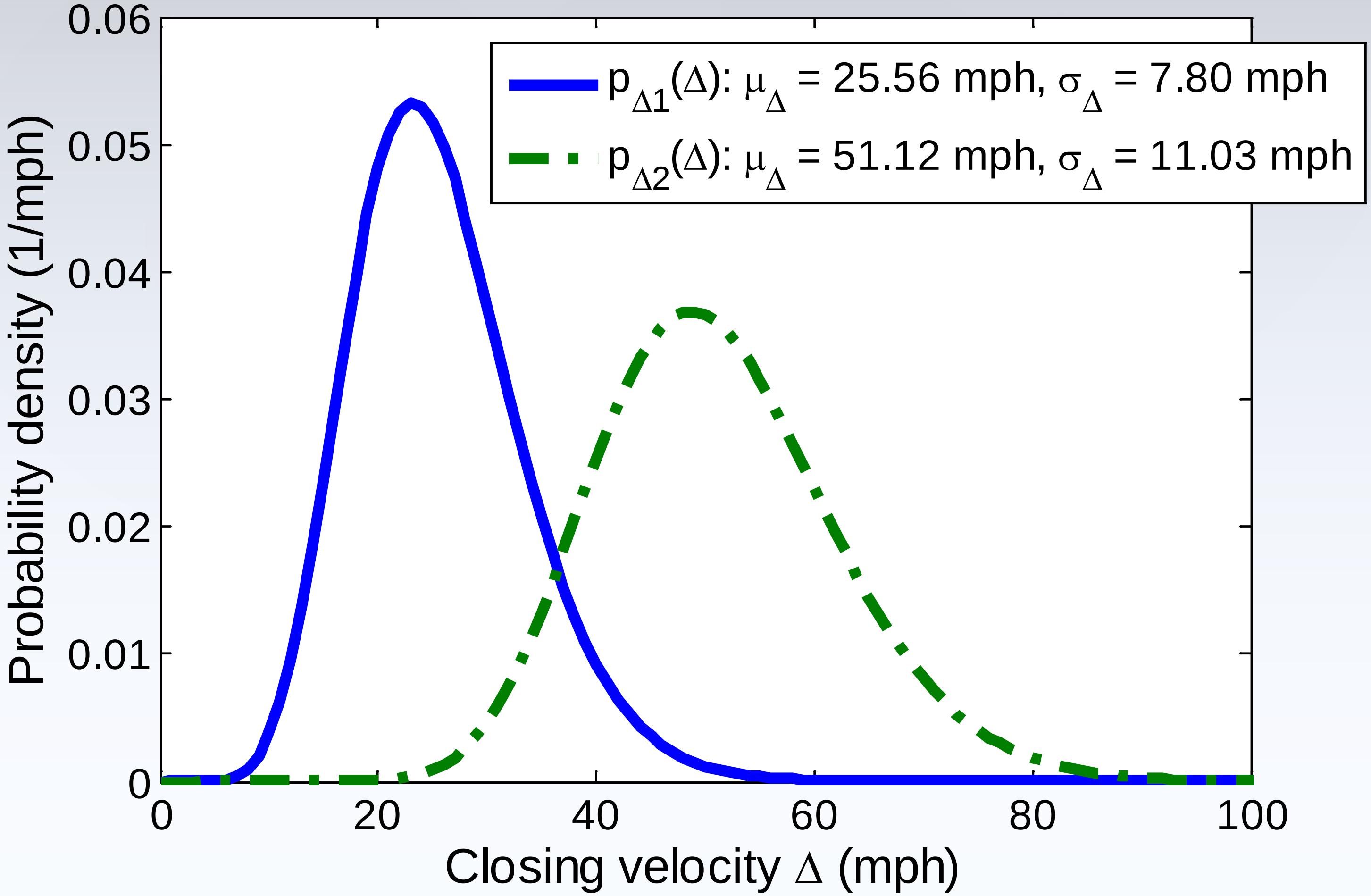


Application: from ratio to risk

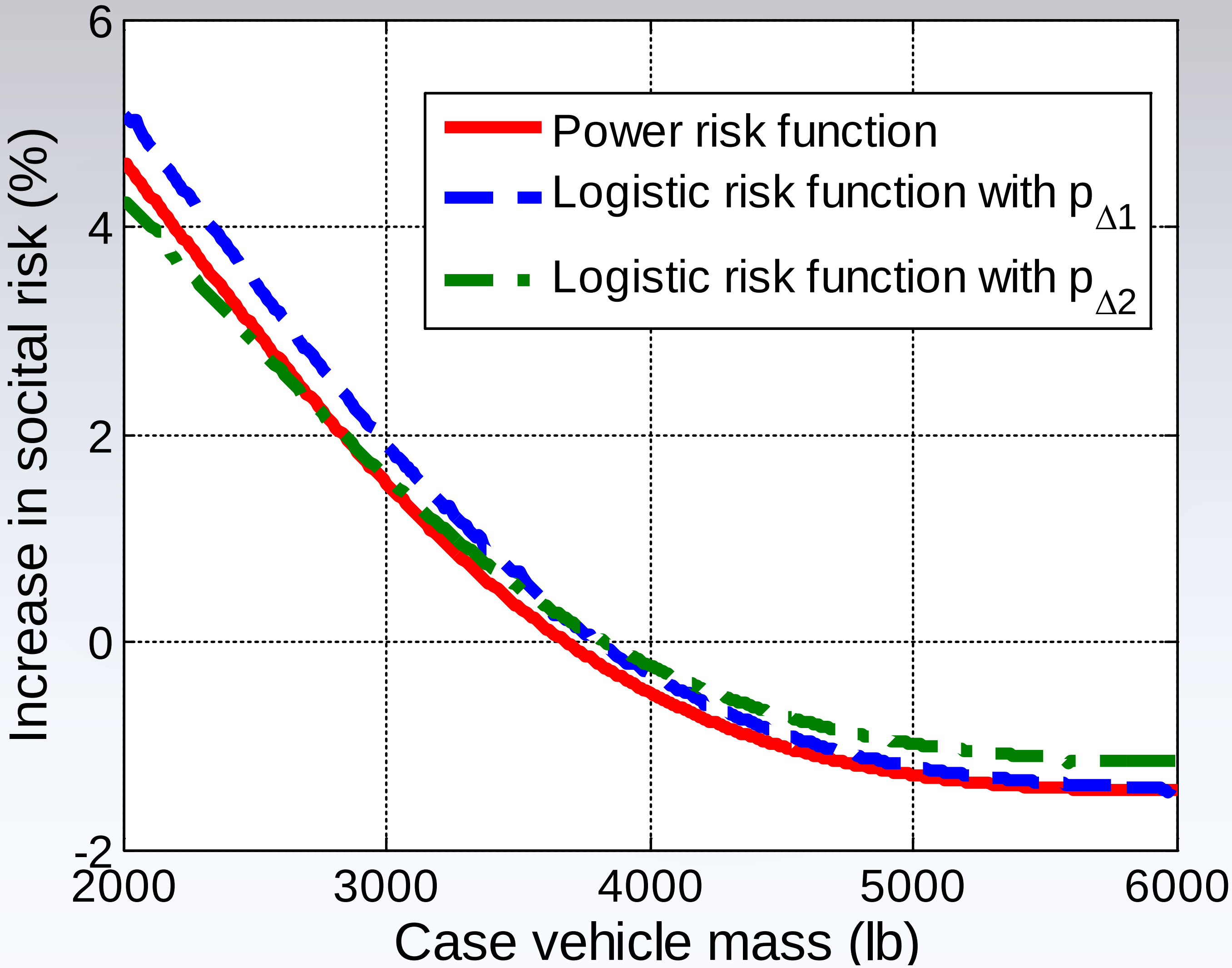


Closing Velocity Distribution

$$\bar{\bar{r}}_1(m_1) = k \iint \frac{1}{1 + \left(\frac{\Delta}{2v_{0p}}\right)^{\mu} \left(\frac{2m_2}{m_1 + m_2}\right)^{\mu}} p_\Delta(\Delta) \cdot p_m(m_2) d\Delta dm_2$$

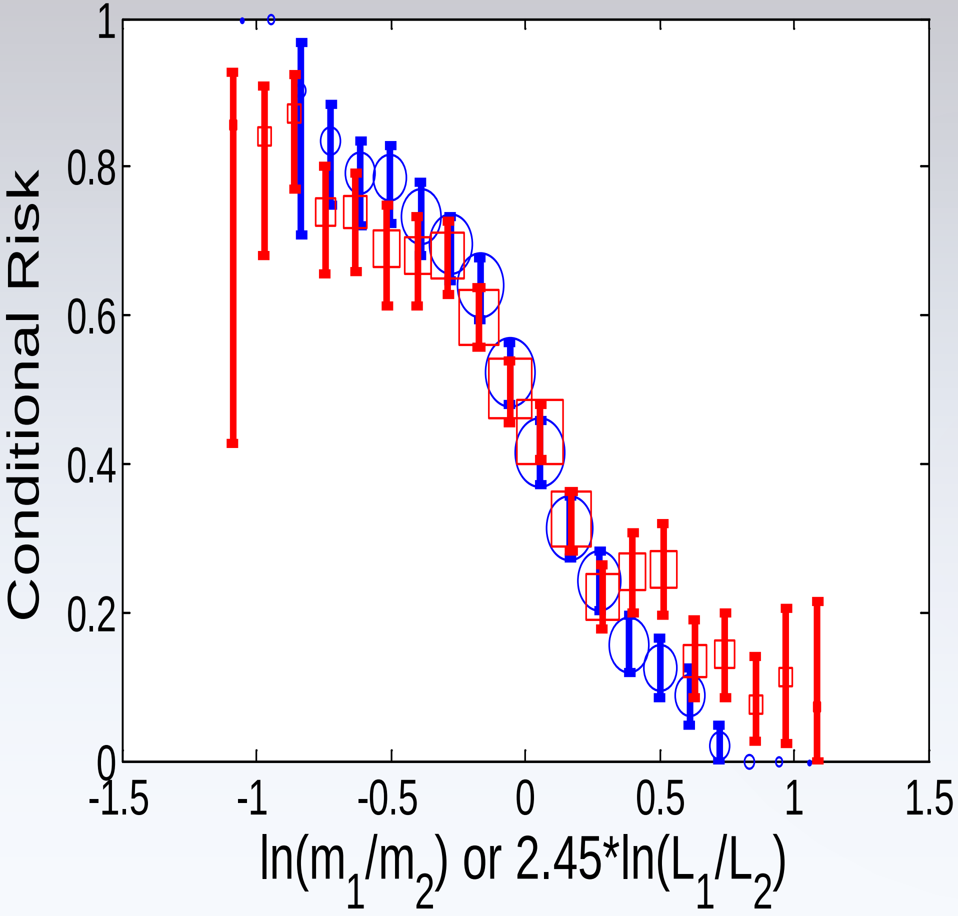


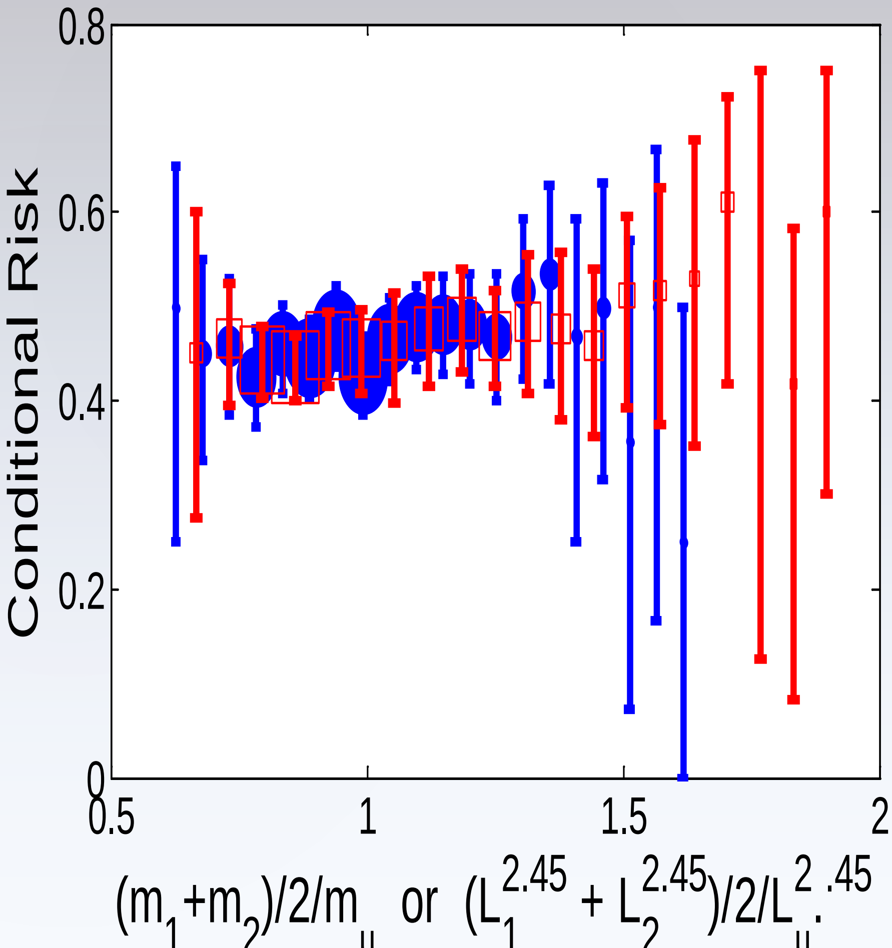
Fleet Risk Sensitivity to Risk Function (and Closing Velocity Distribution)



Risk increase per 100 lb of decrease in subject vehicle mass

Discussion: Mass vs. length





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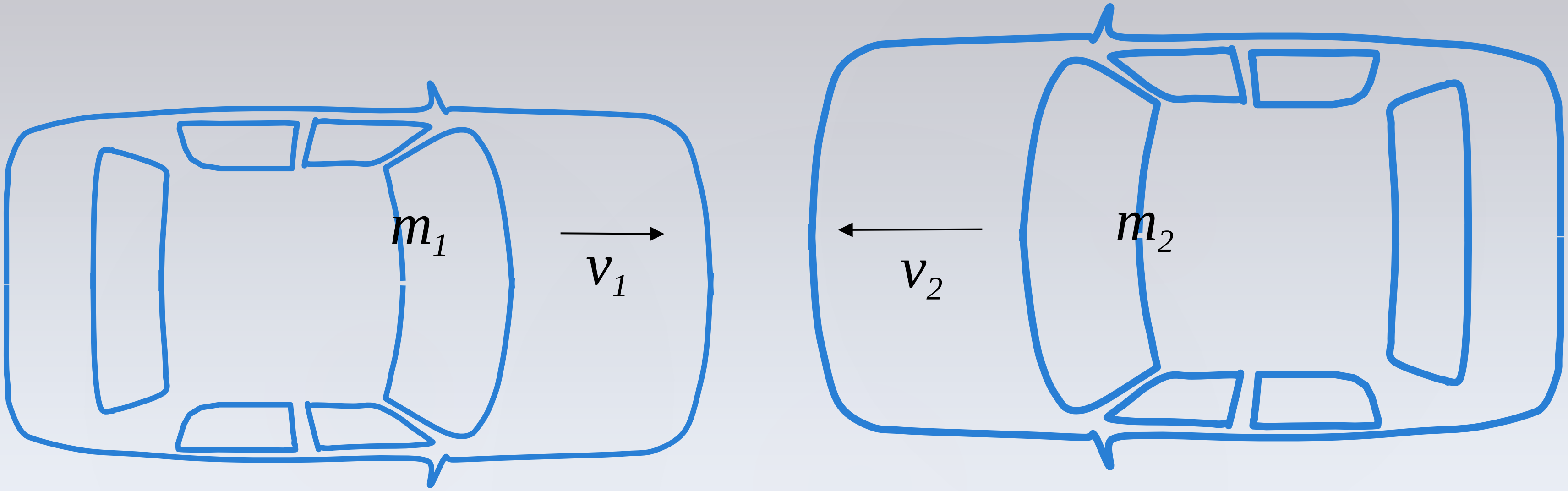
Effect of Mass on Velocity Change

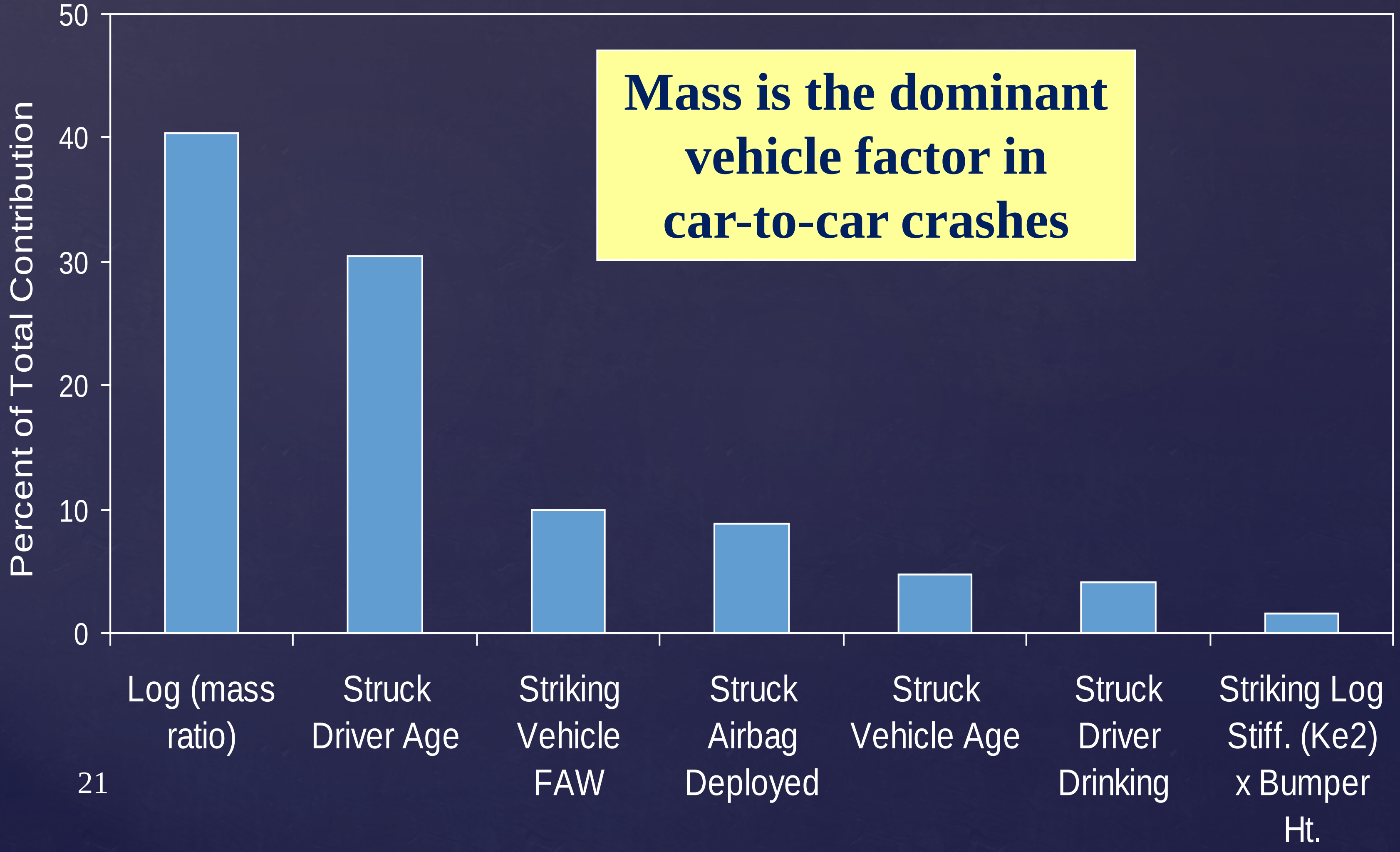


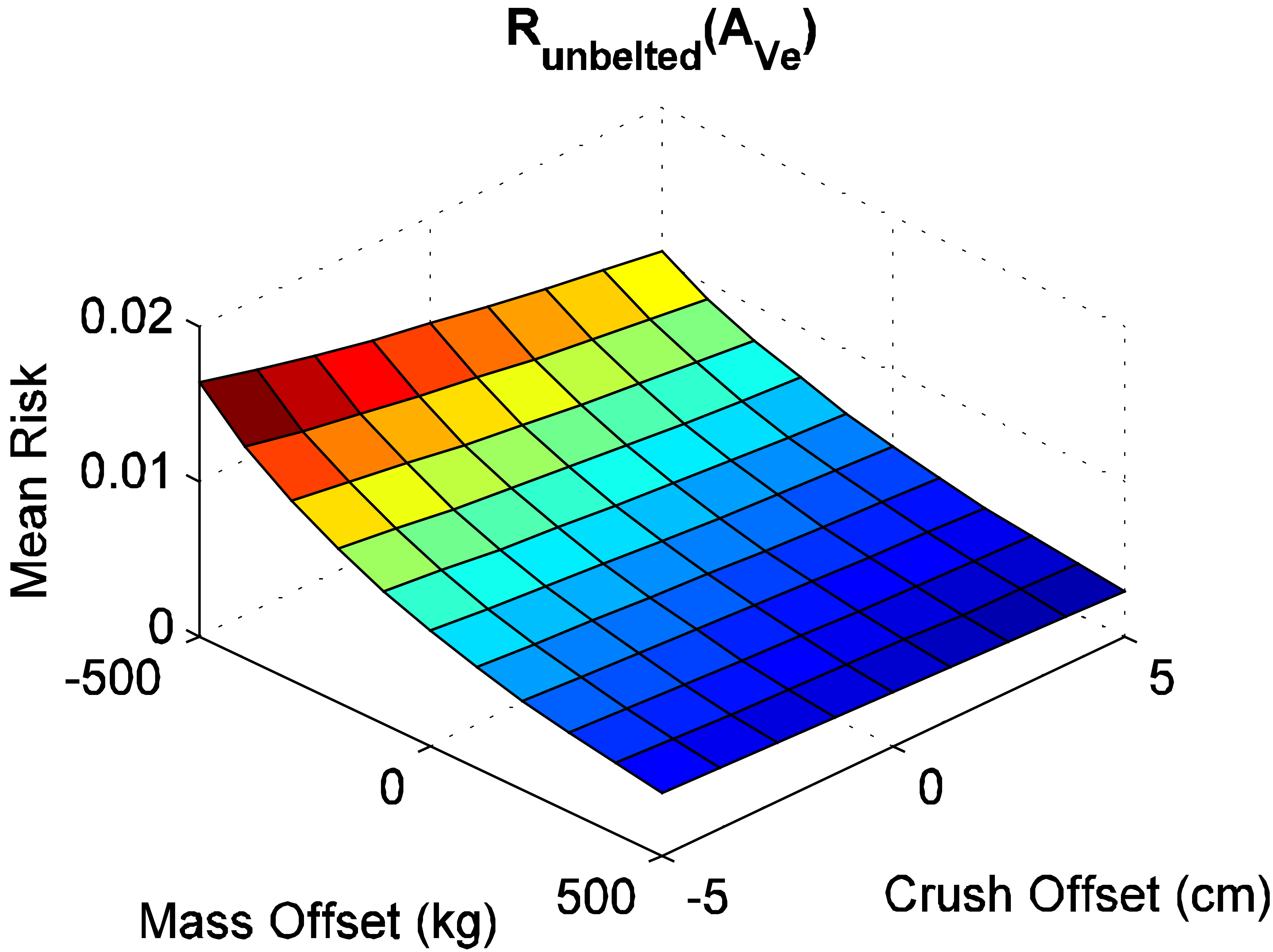
$$\left|\Delta v_1\right| = \frac{m_2}{m_1 + m_2}\left(\left|v_1\right| + \left|v_2\right|\right) \qquad \left|\Delta v_2\right| = \frac{m_1}{m_1 + m_2}\left(\left|v_1\right| + \left|v_2\right|\right)$$

For $m_1 = 2500\, lb,\ m_2 = 3500\, lb,$ and $\left|v_1\right| + \left|v_2\right| = 50\, mph,$

Δv_1 ~~20~~ $= 29.2\, mph, \qquad \Delta v_2 = 20.8\, mph.$

Relative Contribution of Variables to Odds of Fatality Car-to-Car, Frontal Crashes





$R_{unbelted}(A_{Ve})$
Mean Risk
0.02
0.01
0
-500
0
500
Mass Offset (kg)
-5
0
5
Crush Offset (cm)

Example of Kahane [2012] Analysis Result

100-lb Mass Reduction Cars < 3,106 lb, Holding Footprint Constant

Crash Type	Point estimate (%)	95% Confidence bounds (%)	
		Lower	Upper
1st-event Rollover	-2.16	-4.65	0.33
Hit fixed object	-0.68	-2.40	1.05
Hit pedestrian/bike/motorcycle	1.95	0.07	3.84
Hit heavy vehicle	2.14	-1.26	5.54
Hit car-CUV-minivan < 3,082 lb	0.68	-1.61	2.98
Hit car-CUV-minivan > 3,082 lb	0.37	-2.44	3.17
Hit truck-based LTV < 4,150 lb	1.10	-1.98	4.18
Hit truck-based LTV > 4,150 lb	5.97	3.18	8.76
All others	1.85	-0.38	4.08

V-V Crashes: [EM1 Conservation of Momentum EM2] → r(m; …)

CE + Fully plastic: $v_1 = \frac{m_2}{m_1+m_2}\Delta$ & $v_2 = \frac{m_1}{m_1+m_2}\Delta$

Sub. into EM1: $r_1 = \left(\frac{2m_2}{m_1+m_2}\right)^{\alpha}\left(\frac{\Delta}{2v_{0p}}\right)^{\alpha}$ & $r_2 = \left(\frac{2m_1}{m_1+m_2}\right)^{\alpha}\left(\frac{\Delta}{2v_{0p}}\right)^{\alpha}$

→ $\frac{r_1}{r_2} = \left(\frac{m_2}{m_1}\right)^{a}$ ⟷ $\frac{r_1}{r_2} = k_{D_{VTYP}} \cdot k_{D_{ESC}} \cdot k_{D_{Belt}} \cdot k_{D_{Age}} \left(\frac{m_2}{m_1}\right)^{\beta}$

$$r_1(m_1, m_2, \Delta; \beta, v_{0p}; \dots) = k_D \left(\frac{2m_2}{m_1+m_2}\right)^{\beta}\left(\frac{\Delta}{2v_{0p}}\right)^{\beta}$$

Form from EM1; mass brought in with Conservation of momentum;
β (& other effects) from EM2.

Fleet average risk

Averaged over crash vel. dist. & other vehicle mass
-> subject vehicle Ave. Risk

$$\bar{\bar{r}}_1(m_1) = k \iint \left(\frac{\Delta}{2v_{0p}}\right)^{\alpha} \left(\frac{2m_2}{m_1+m_2}\right)^{\alpha} p_{\Delta}(\Delta) p_m(m_2) d\Delta dm_2$$

$$= kC \cdot \int \left(\frac{2m_2}{m_1+m_2}\right)^{\alpha} p_m(m_2) dm_2$$

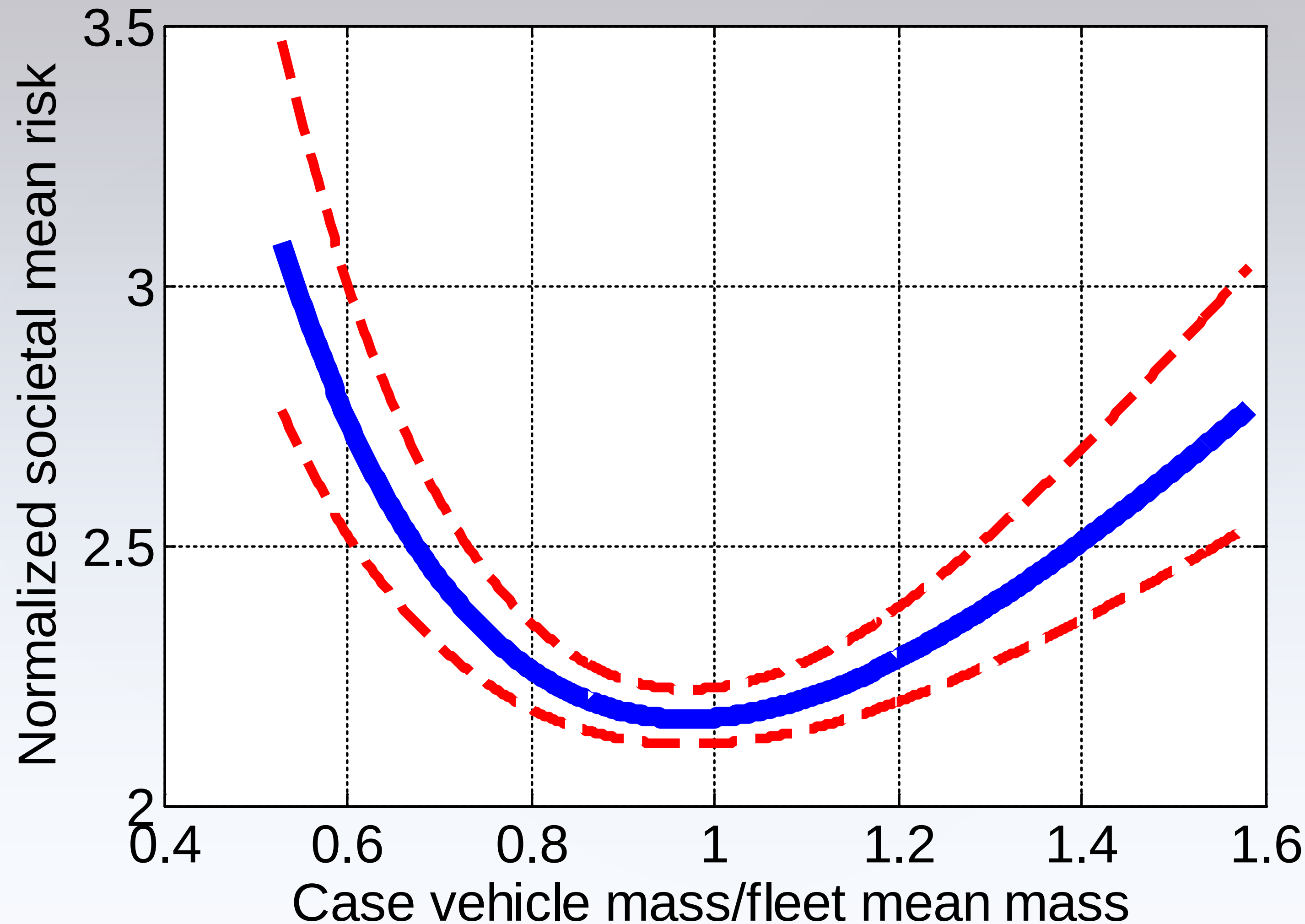
Sum of two vehicles → "societal risk"

$$\bar{\bar{s}}(m_1) \triangleq \bar{\bar{r}}_1(m_1) + \bar{\bar{r}}_2(m_1)$$

$$= C \int \left\{ \left(\frac{2m_1}{m_1 + m_2}\right)^{\alpha} + \left(\frac{2m_2}{m_1 + m_2}\right)^{\alpha} \right\} p_m(m_2)\, dm_2$$

Next: Evaluate with given $p_m(m)$; compare with Kahane result

Result – "societal risk", given subject vehicle



Power function risk (EM1); Risk exponent (3.83+-0.26) → [3.24 4.34] 95% CI; $p_m(m)$

Independent of $p_\Delta(\Delta)$ (therefore normalized)

Reduction of Kahane Result

Kahane result mainly used in the context of:

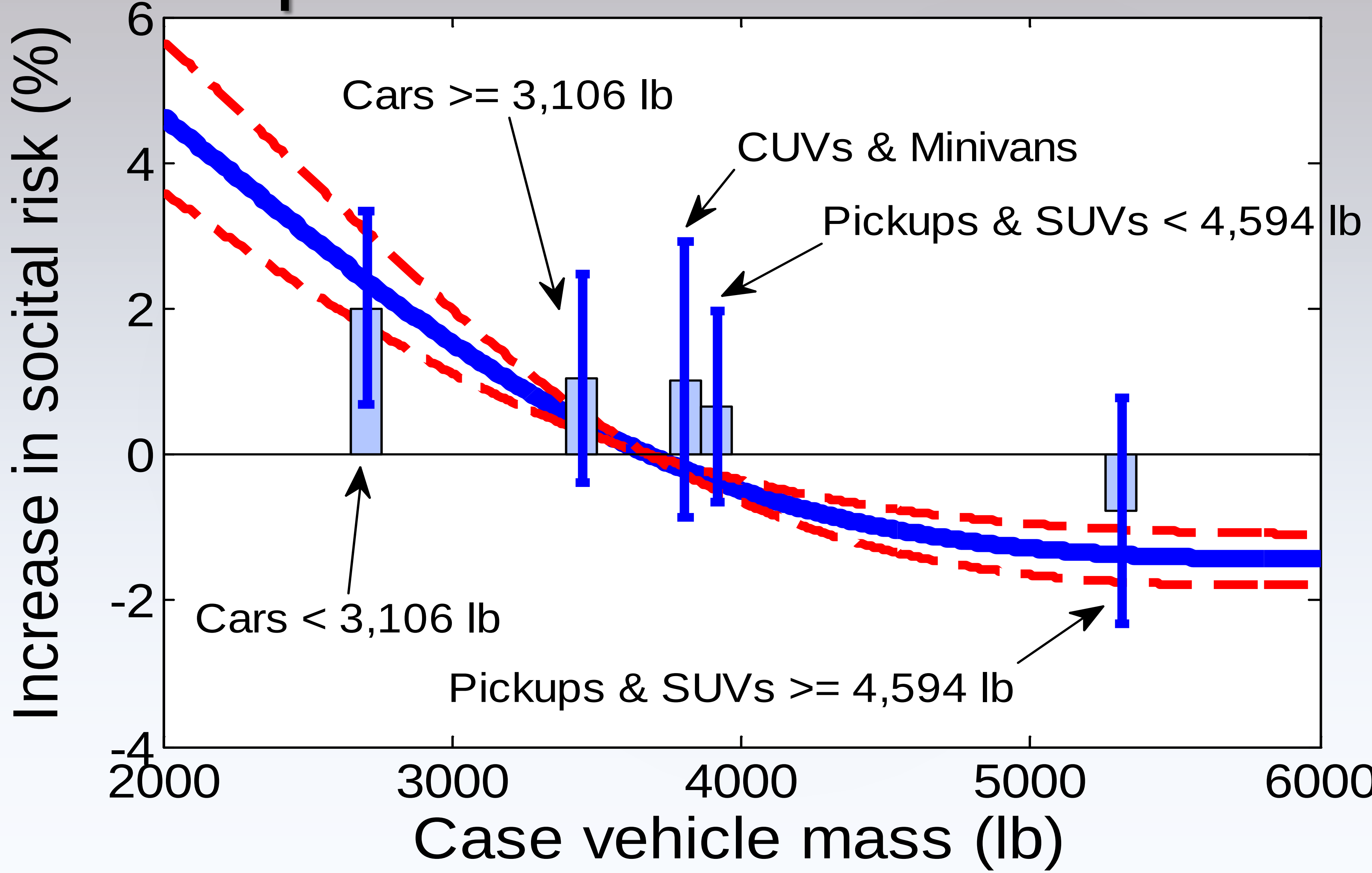
Percent increase in societal fatality rate per 100 lb decrease in subject vehicle mass

$$\bar{\bar{s}}(m) = C \int \left\{ \left(\frac{2m}{m + m_o} \right)^{\alpha} + \left(\frac{2m_o}{m + m_o} \right)^{\alpha} \right\} p_m(m_o)\, dm_o$$

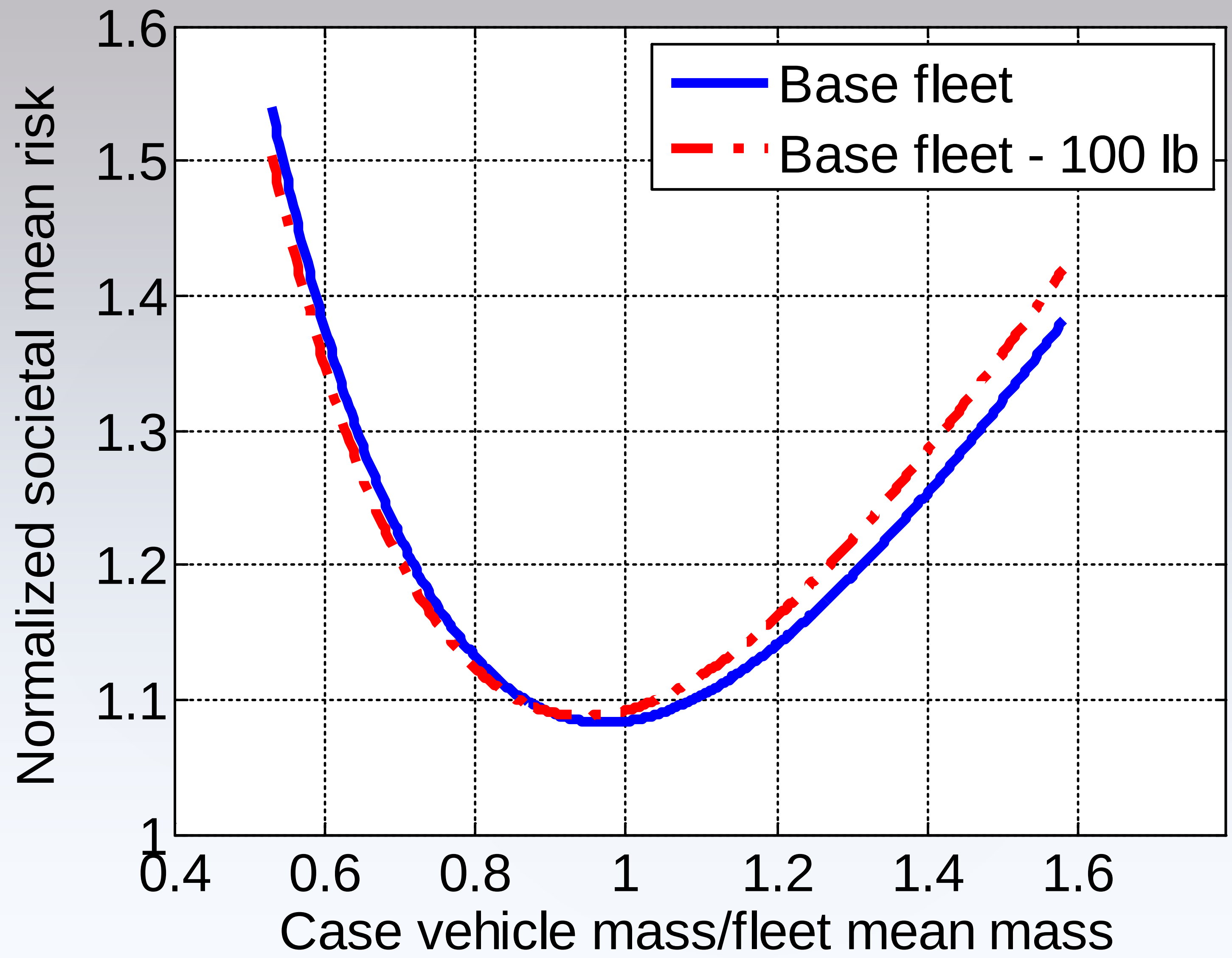
$$RRR(m) \triangleq \frac{1}{\bar{\bar{s}}(m)} \frac{d\bar{\bar{s}}(m)}{dm}$$

"Relative Rate of change of societal Risk for subject vehicle of mass *m*

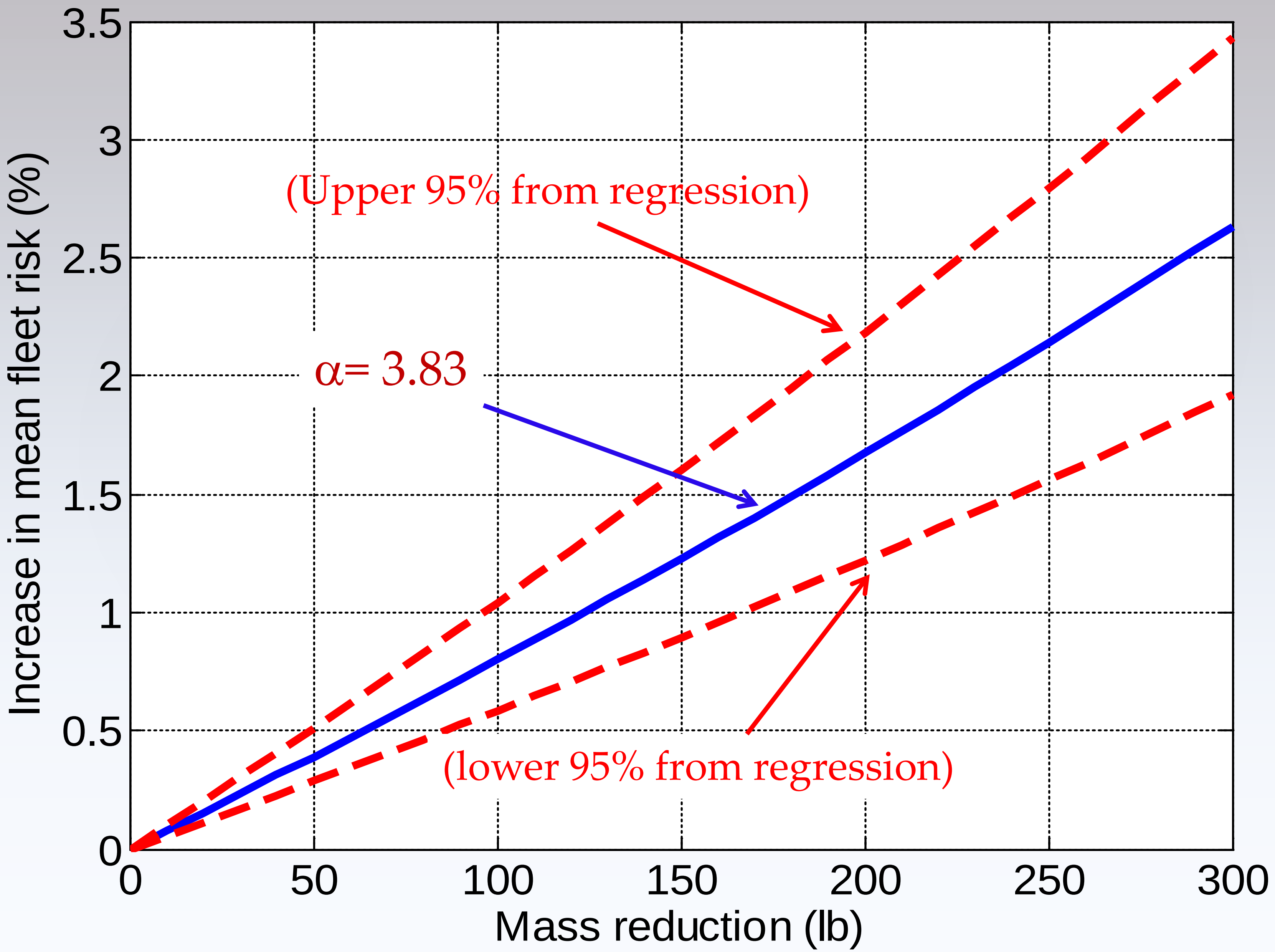
Comparison



Increase in societal risk for 100 lb case vehicle mass reduction



Note: Case vehicle for both fleets normalized by based fleet mean mass



(Upper 95% from regression)
α= 3.83
(lower 95% from regression)
Increase in mean fleet risk (%)
Mass reduction (lb)
0
0.5
1
1.5
2
2.5
3
3.5
0
50
100
150
200
250
300

Summary & Conclusions --1

- A fleet fatality risk model has been established (again). Assuming
  - Conservation of momentum, energy
  - $r(v)$ empirical relationship(accident data)
  - Current distribution of vehicle parameters
- Then
  - Model societal risk change due to mass change comparable to Kahane 2012 result
  - *Consistent* r_1/r_2 v.s. m_1/m_2 *(accident data)*

Summary & Conclusions -- 2

- Kahane's result appears to be in essence a manifestation of the two relationships: velocity (risk) and C.M.
- Model uncertainty examined via risk exponent; risk functional form (& velocity distribution); Result: model is stable.
- For the observed variation mass has a greater effect on risk than other parameters, such as stiffness, crush, wheel base..etc.

Summary & Conclusions -- 2

- For Front-Front crashes:
  - Mass ratio risk exponent ~ 3.8 Consistent with existing data. Reflection of conservation of momentum and velocity risk
  - Belted: ~0.3x relative to unbelted
  - 10-years age increase above the 30-38 year range (lowest fatality risk): ~ 1.5x

Summary & Conclusions -- 3

- For Front-Left crashes:
  - R_bullet: R_target ~= 1:8, when all other parameters are equal.
  - Mass ratio risk exponent ~= 4.2, slightly larger
  - Driver age was found to influence driver fatality risk

Summary & Conclusions -- 4

- The effect of Mass on societal risk:
  - Risk from Crash velocity
  - Conservation of Momentum
  - **Parameter distribution: mass, stiffness, available, size crush…etc. Dictates results**
- The regression result may be used to model risk.

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