The Relationship between Vehicle Weight, Size and Safety

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Improvements in both fuel economy and safety are possible

- Fuel economy improvement is cost-effective (Greene 2007, EEA 2006)…
  - —technologies exist to raise fuel economy 50%, at current gas prices ($3.00/gallon)
  - —includes some weight reduction in only heaviest pickups
  - —does not include new powertrains (hybrid, plug-in hybrid, HCCI, fuel cells) or fuels (diesel, low-carbon fuels)
  - —more technologies become cost-effective as gas price increases
- …but weight reduction is easiest, and least-costly, step to increase fuel economy
- Advanced materials (high-strength steel, advanced composites) may allow large weight reductions, and fuel economy improvement, without any sacrifice in safety
- Safety can be improved using new technologies, with little impact on weight or fuel economy
  - —electronic stability control
  - —better seat belts
  - —stronger roofs
  - —vehicle-to-vehicle communication

Two views on vehicle weight and safety

- Majority of National Academy of Sciences committee on the Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (2002):
  - "The downweighting and downsizing [of vehicles] that occurred in the late 1970s and early 1980s, some of which was due to CAFE standards, probably resulted in an additional 1,300 to 2,600 traffic fatalities in 1993."
- Minority (two members) of same committee:
  - "The conclusions of the majority of the committee … are overly simplistic and at least partially incorrect … The relationship between vehicle weight and safety are complex and not measureable with any reasonable degree of certainty at present…Reducing the weights of light-duty vehicles will neither benefit nor harm all highway users; there will be winners and losers."
- Does reducing weight inherently increase fatalities, or not?

Conclusion: “weight” and “size” provide only partial protection

- Crashes with another vehicle or stationary object
  - reducing <u>weight ratio</u> would reduce deceleration of lighter vehicle
  - <u>crush space</u> improves crashworthiness, but difficult to provide when struck in side
  - <u>height and structure</u> of “bullet” vehicle are more important
- Vehicles struck in side
  - heavier and larger light trucks are much more aggressive to other vehicles than lighter and smaller light trucks
  - reducing frontal height and perhaps stiffness of light trucks is necessary to reduce their aggressivity
  - increasing side stiffness or crush space in cars could improve their compatibility
- Rollover crashes
  - weight has little effect on propensity to roll over
    - width, and to a lesser extent length, can reduce rollover propensity
    - height probably more important even than width
  - electronic stability control promising technology to prevent rollovers

Definition of risk

- "Risk": driver fatalities per year, per million vehicles registered as of Jan 2005
  - driver fatalities from NHTSA Fatality Analysis Reporting System (FARS)
    - FARS includes many details on all US traffic fatalities
  - registered vehicles as denominator, or measure of "exposure"
- Because it is based on actual fatalities, our definition of risk incorporates:
  - vehicle design
    - crash avoidance (sometimes measured by consumer groups)
    - crashworthiness (typically measured in artificial lab crash tests)
  - driver characteristics and behavior
  - road environment and conditions
- Therefore, all risks are "as driven"; as a result, our risks don't correlate well with lab crash test results

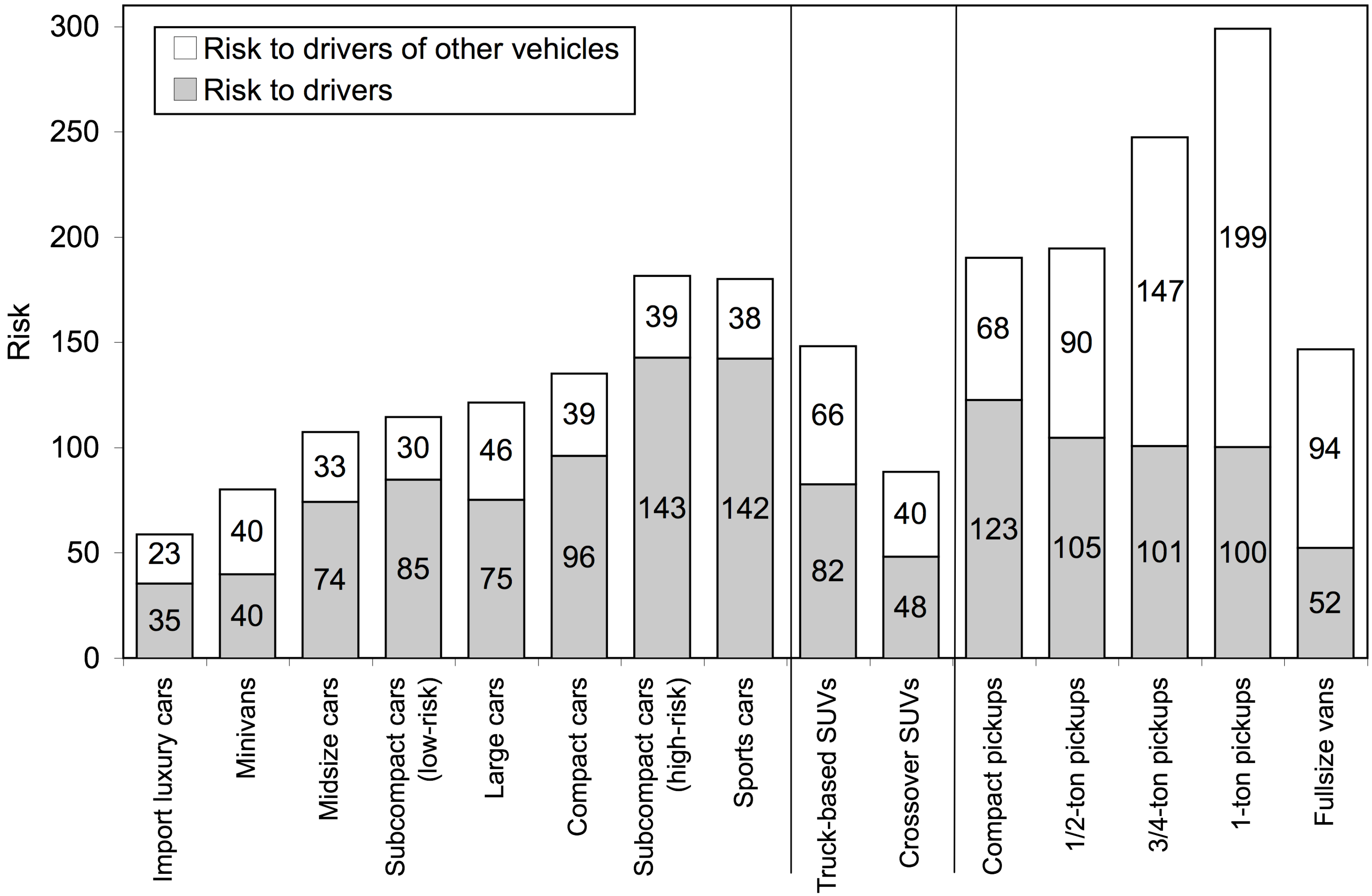
Two types of risk

- Risk to drivers of subject vehicle
  - from all types of crashes (total, and separately for two-vehicle crashes, one-vehicle crashes, rollovers, etc.)
- Risk imposed by subject vehicle on drivers of other vehicles (all types and ages)
  - often called vehicle “aggressivity” or “compatibility”
  - because from two-vehicle crashes only, risks to other drivers tend to be lower than risks to drivers
- Combined risk is the sum of the two

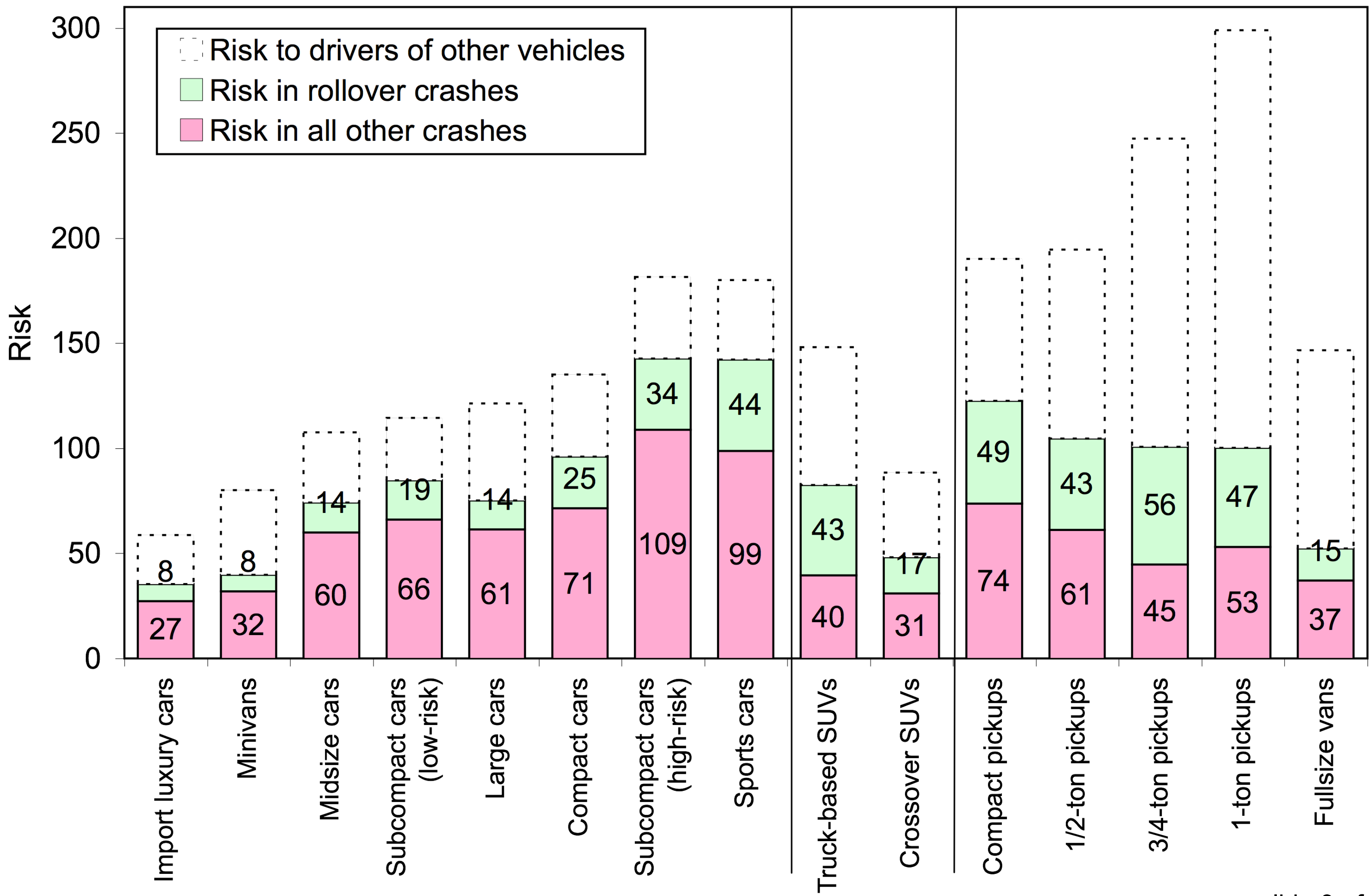
Two levels of analysis

- Risks by vehicle type
  - four major car classes (plus luxury import and sports cars), based on Consumer Guide
  - pickups by size, SUVs, and minivans
  - calculated for 133 popular vehicle models with relatively consistent, strong sales over 2000-04
  - differences less than ~10% not statistically significant
- Risks by vehicle model
  - calculated using only 69 most popular vehicle models, to reduce statistical uncertainty
  - differences less than ~20% not statistically significant

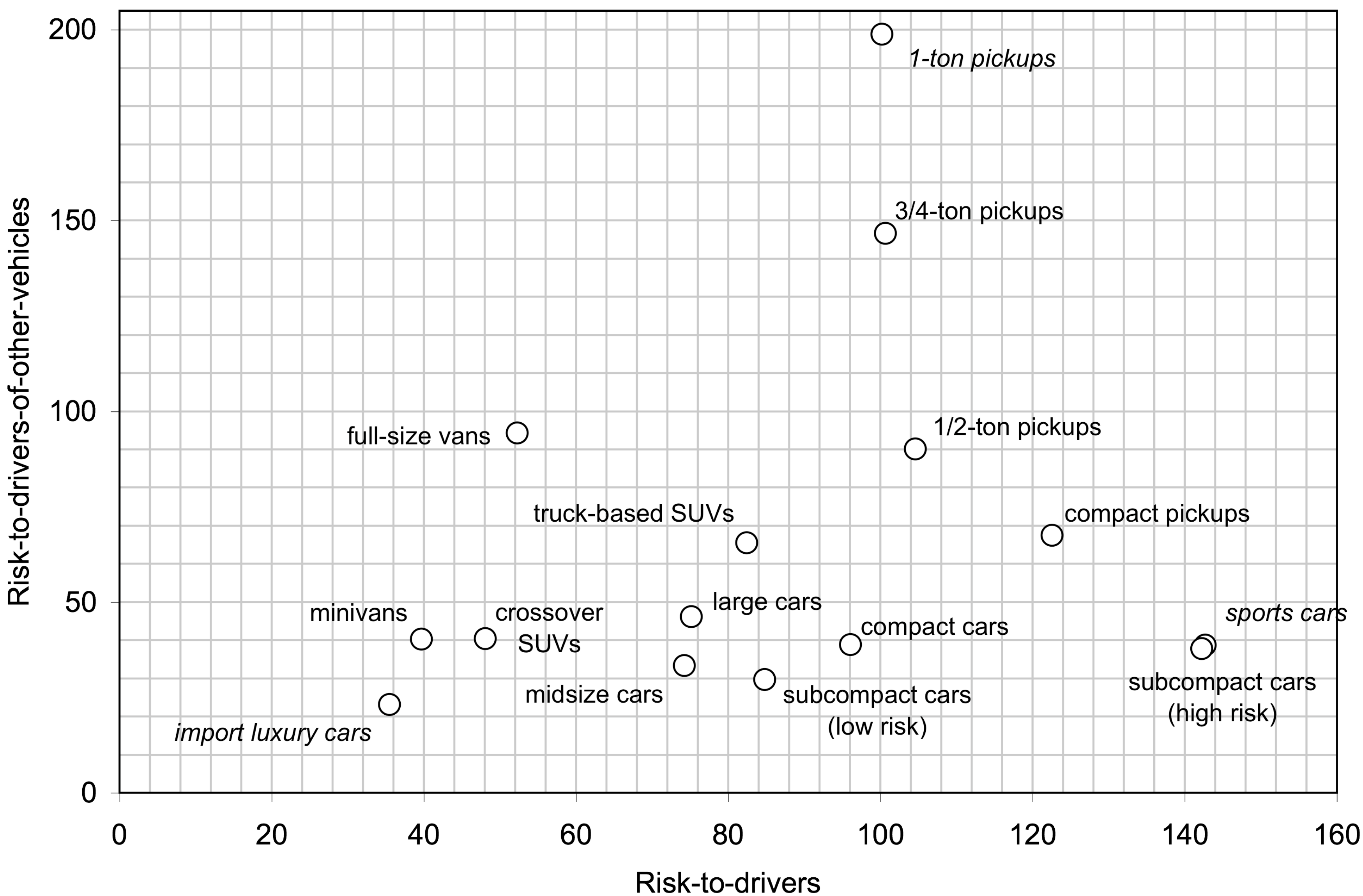
Risks by vehicle type



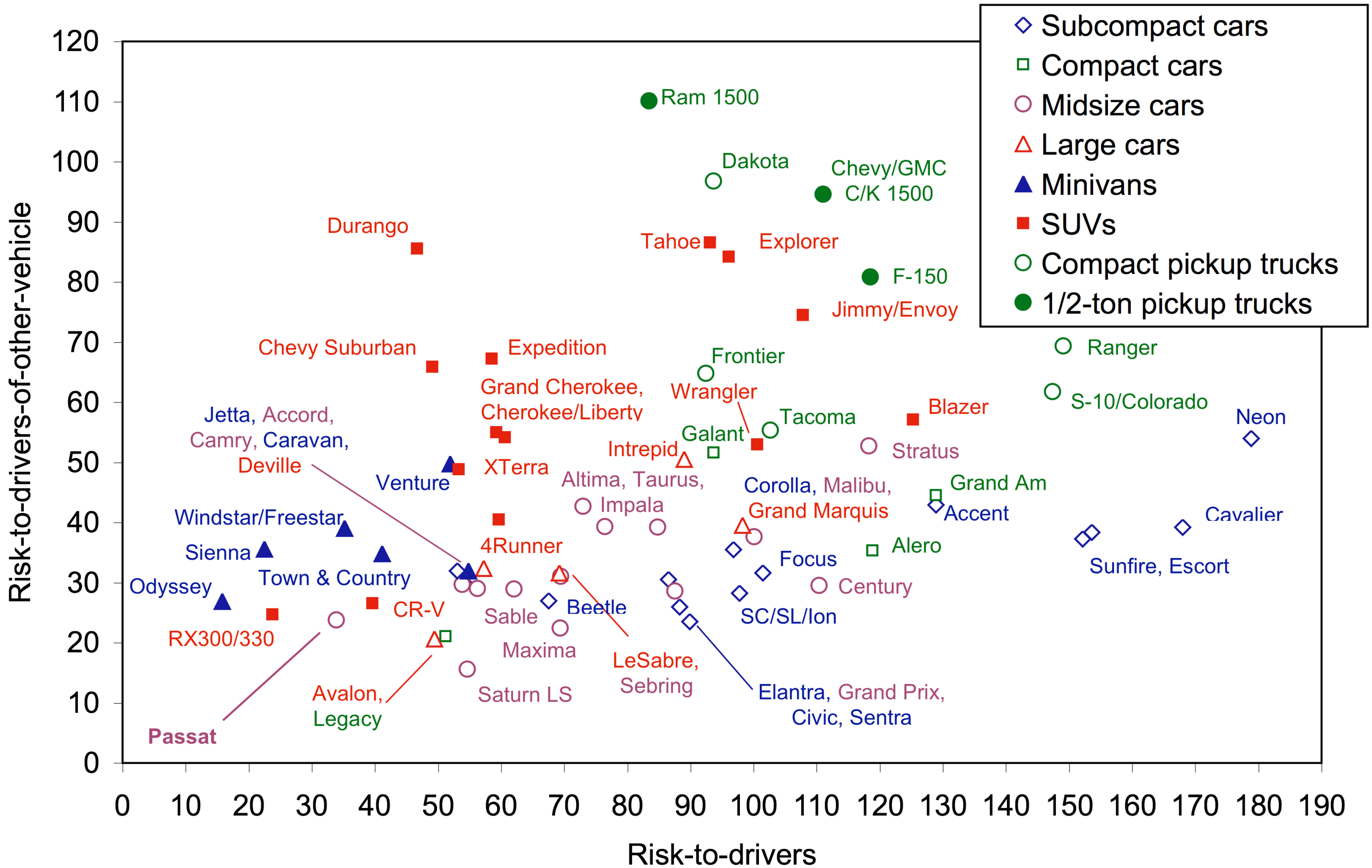
Risk to drivers in rollovers and all other crashes



Risks by vehicle type



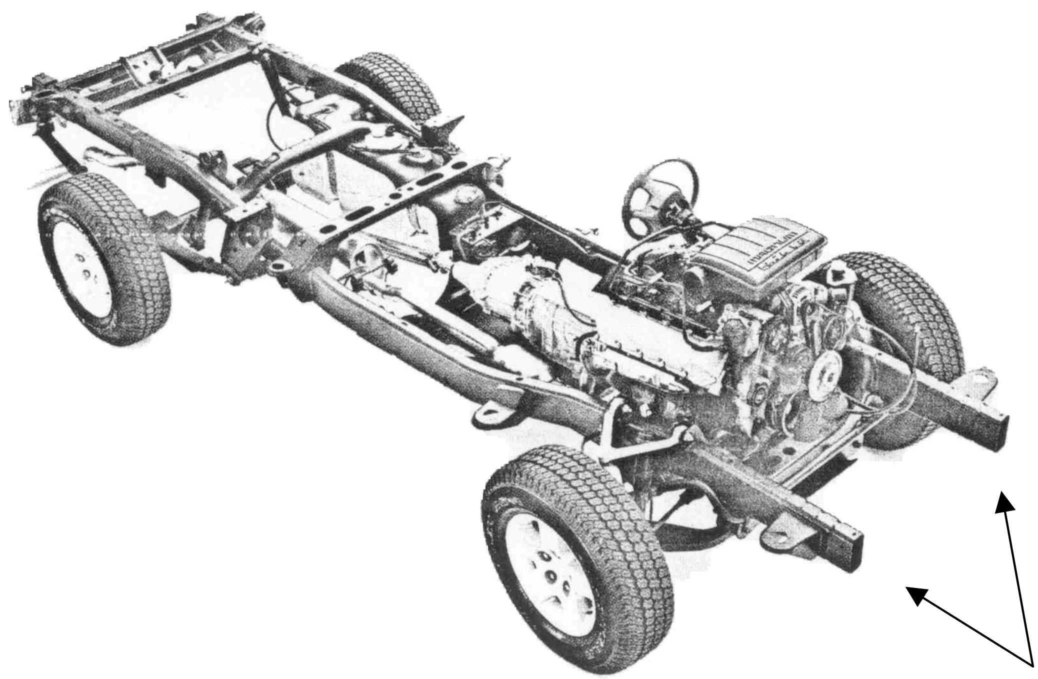
Risks by vehicle model



Effect of vehicle design on risk

- High risk to drivers of pickups and SUVs from their propensity to roll over
  - NHTSA's static stability factor (SSF): tw/2h
    tw = track width; h = height of center of gravity
  - average car SSF is 1.40, 12% chance of rollover in a crash
  - average SUV SSF is 1.15, 28% chance of rollover
- High risk to others from pickups and SUVs (and to a lesser extent minivans) associated with chassis stiffness and height
  - car driver fatality rate is 5x higher when struck in side by SUV (4x higher when struck by pickup) than when struck in side by another car
  - SUVs are built on pickup frames, whose rails often override car bumpers and sills and puncture car bodies
- Rollover risk in SUVs, especially crossovers, and risk to others from pickups are declining

Stiff frame rails of pickups and truck-based SUVs act as fork tines



MY02 Dodge Ram 150 pickup truck

Driver behavior and environment influence risk

- Driver characteristics that affect risk
  - age and sex
  - alcohol/drug use, driving record
  - seatbelt use
  - education level/income
- Environmental variables that affect risk
  - time of day (visibility)
  - rural roads (poorly lit and designed, high speeds)
  - weather (road conditions)

Effect of driver behavior on risk

- Two measures of driver behavior
  - fraction of fatalities that are young males (<26 years old)
  - bad driver rating based on: alcohol/drug involvement and risky driving in current crash, and driver's record over last two years (lower rating is better drivers)
- Truck-based SUV drivers are very much like car drivers
- Risky sports cars have highest fraction of young male fatalities (39%), and worst drivers (0.77). Safe minivans have the best drivers (4%, 0.21). Safe luxury import cars have slightly worse drivers (21%, 0.57) than the average car (20%, 0.50).
- However, individual models do not necessarily fit these trends
  - the much safer Civic (30%, 0.54) and Jetta (32%, 0.66) have worse drivers than all other subcompacts (22%, 0.54)
  - the risky Blazer/Trailblazer has only slightly worse drivers (18%, 0.50) than the average truck-based SUV (15%, 0.45)

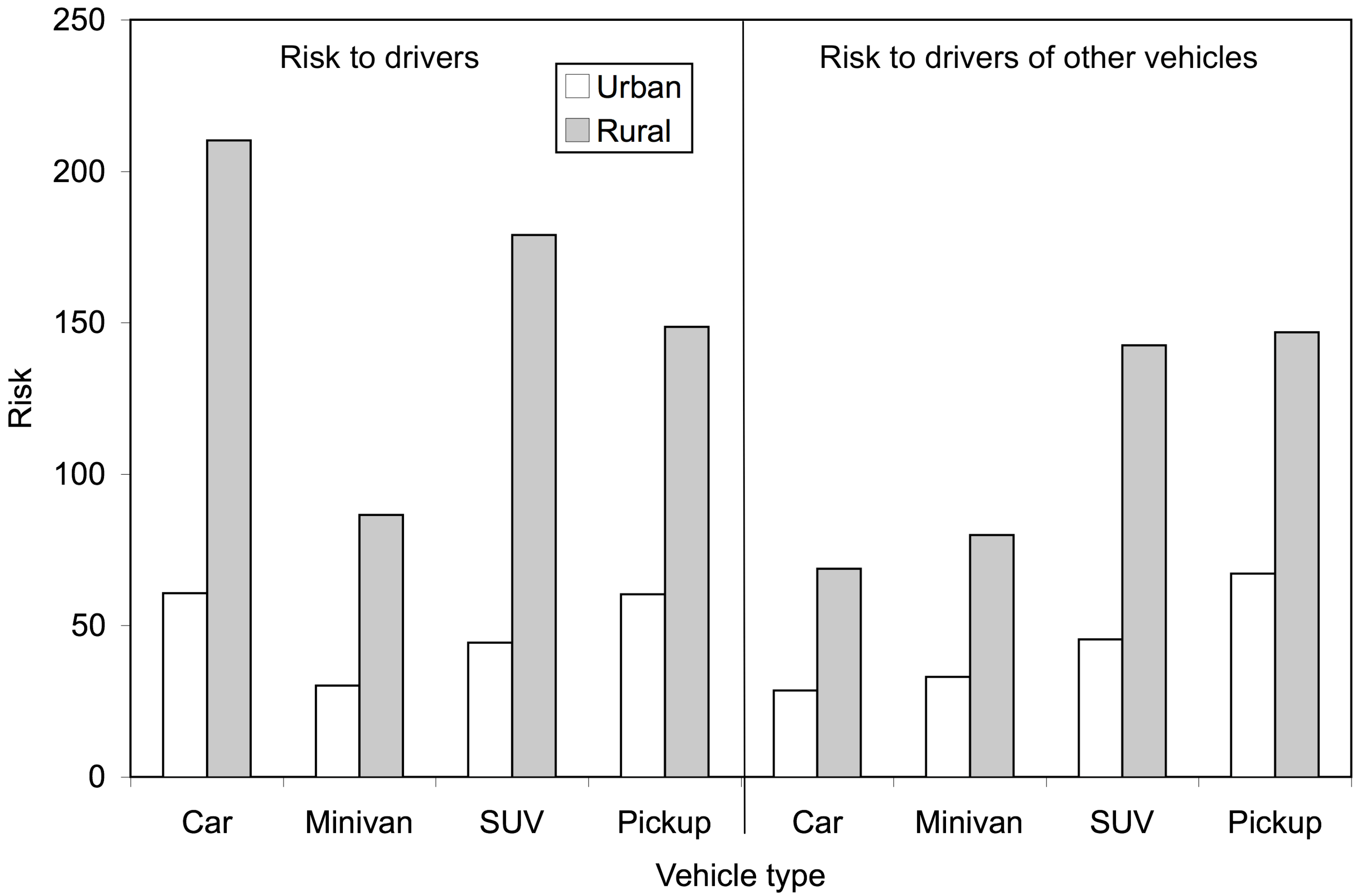
Effect of driver behavior on risk (cont.)

- Station wagons have lower risk, and for the most part better drivers, than sedan/coupe versions of same model
  - Escort/Tracer, Taurus/Sable, Saturn SC/SL/SW, Legacy, Impreza, Volvo have lower risks
  - all but Impreza and Volvo also have better drivers
- Crown Victoria Police Interceptor model has much higher risks (risk in 144, risk by 366) than other Crown Vics (risk in 94, risk by 65)
  - Police Interceptors have more young male drivers (15% v. 5%), but lower bad driver rating (0.20 v. 0.38)
- Some models with higher hp engines have higher risk, and worse drivers, than lower hp engines of same model
  - higher hp engines in Mustang, Camaro, Firebird, Grand Am, and Jetta all have higher risk and worse drivers than lower hp engines in same model
  - but for other models (Camry, Galant, Eclipse, Alero, Lincoln LS) cars with higher hp engines do not have higher risk

Effect of environment on risk

- Rural roads (less well-lit, undivided, higher speeds, unenforced speed limits, further from hospital) are less safe than suburban or urban roads
  - risks much higher in very rural areas
- Pickups are driven more on unsafe rural roads than other vehicle types; the average pickup fatality occurs in much less dense areas (250 people per sq mile) than average SUV or car fatality (340 and 420 people per sq mile, respectively)
- Used California vehicle registrations by county to calculate risk in urban vs. rural counties, by vehicle type

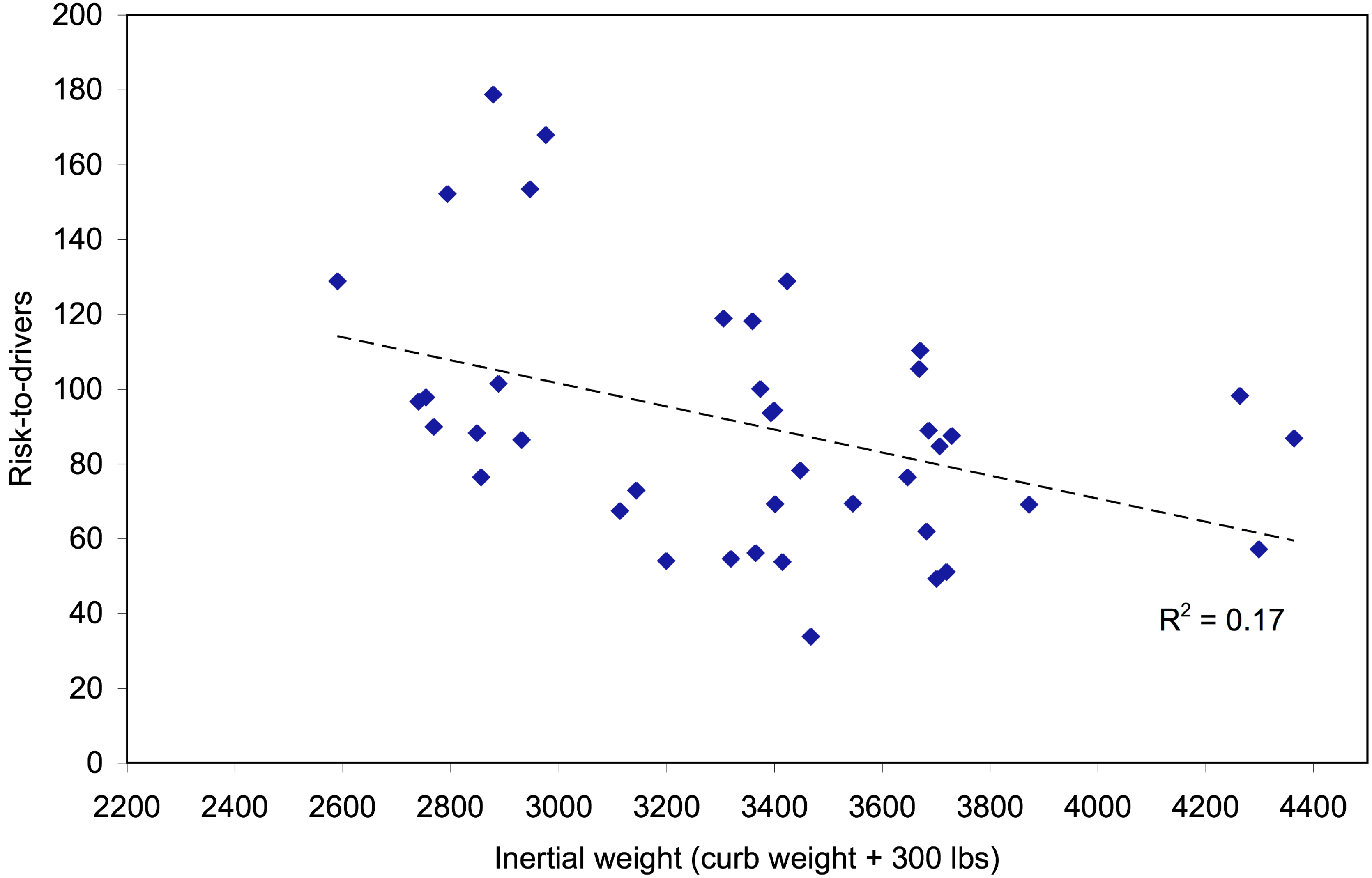
Risks in California are higher in rural areas than in urban areas, for all vehicle types



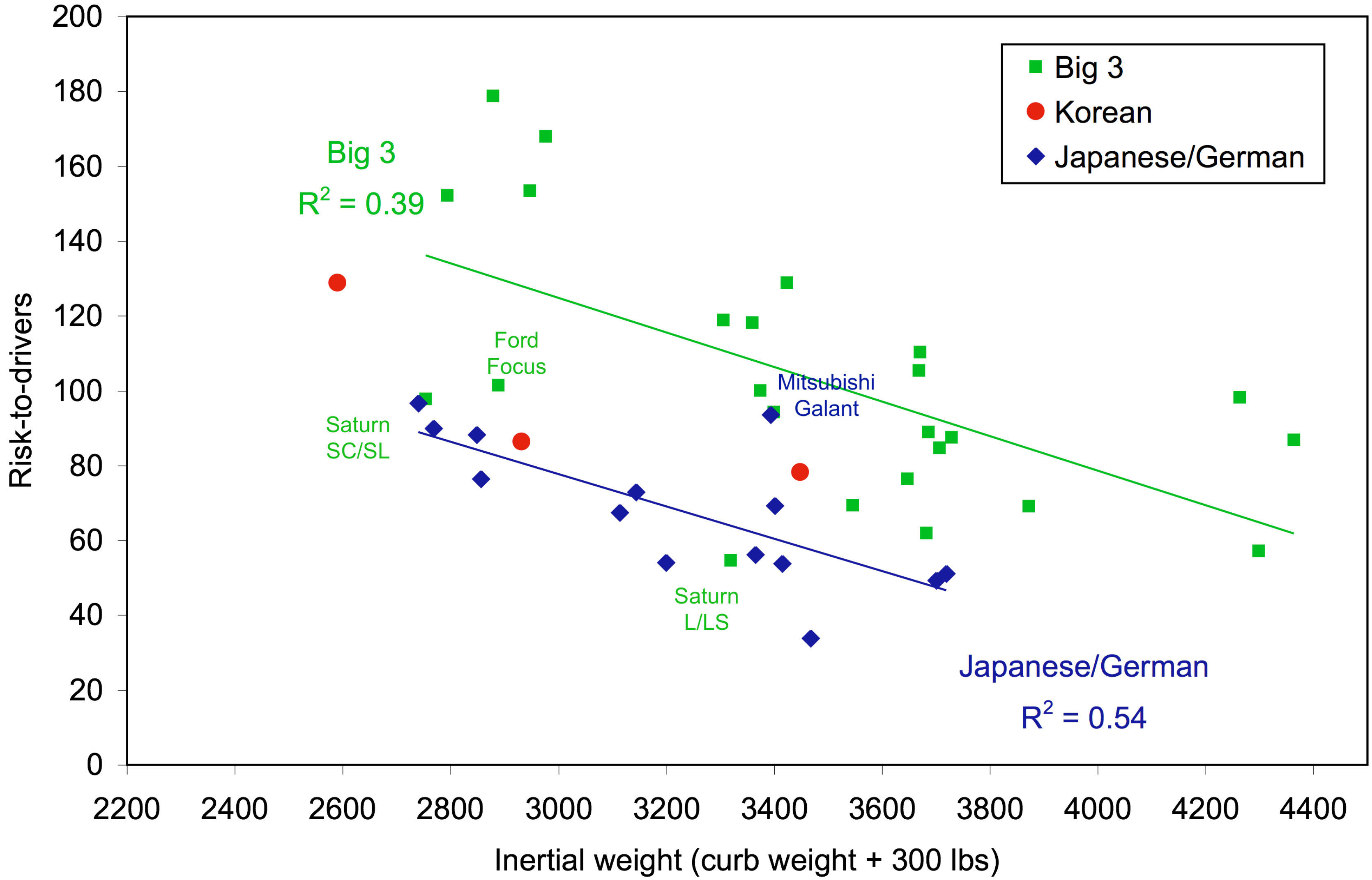
Is car weight the best predictor of risk?

- Quality of vehicle design appears a better predictor of risk than weight
  - manufacturer
  - resale value (retail used car price from Kelley Blue Book)
- Analysis limited to cars; need truck weights by “model” to apply to pickups, SUVs and minivans
- We excluded models overly influenced by their drivers (young males or elderly)

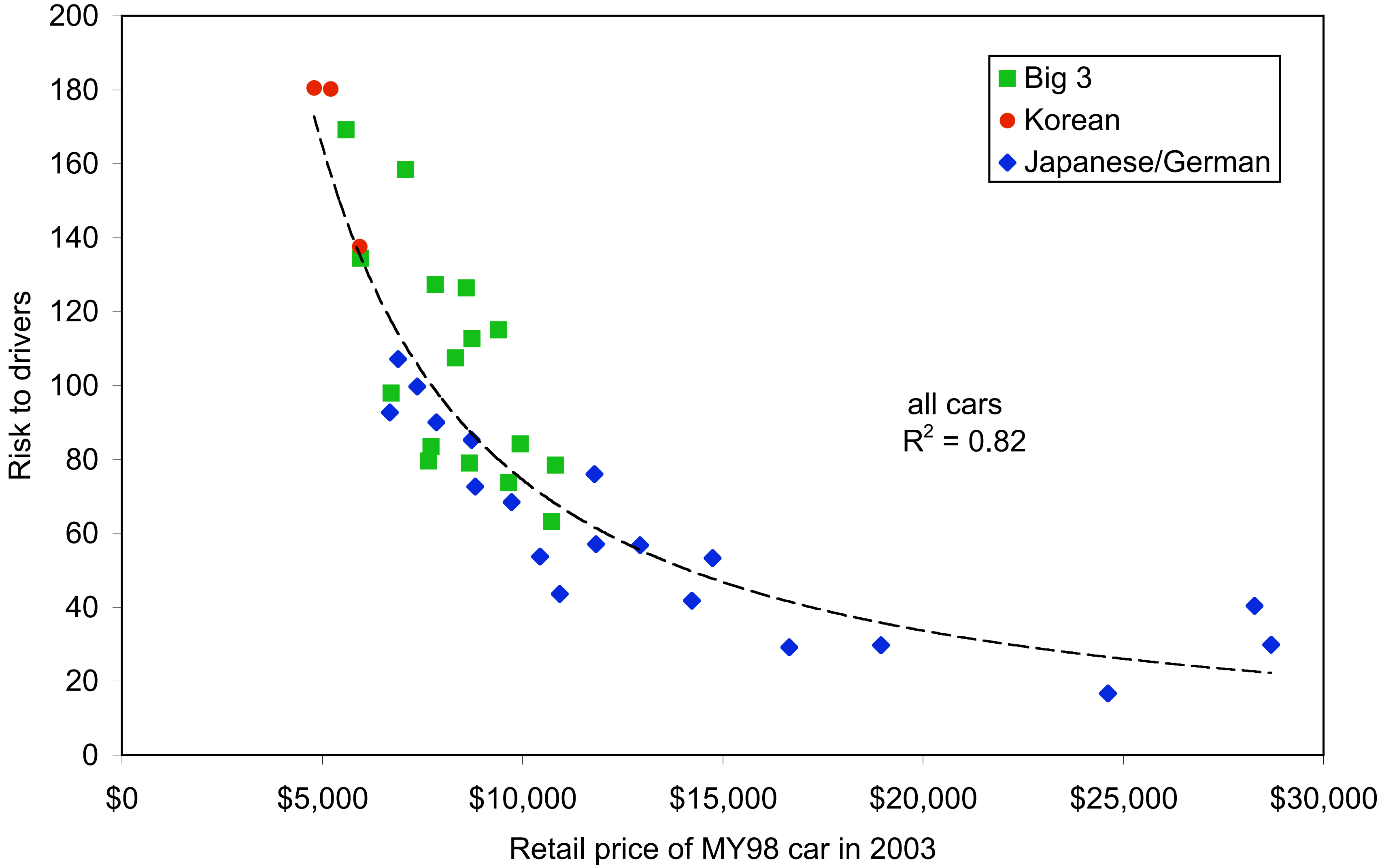
Weak relationship between car weight and risk…



… unless one accounts for manufacturer



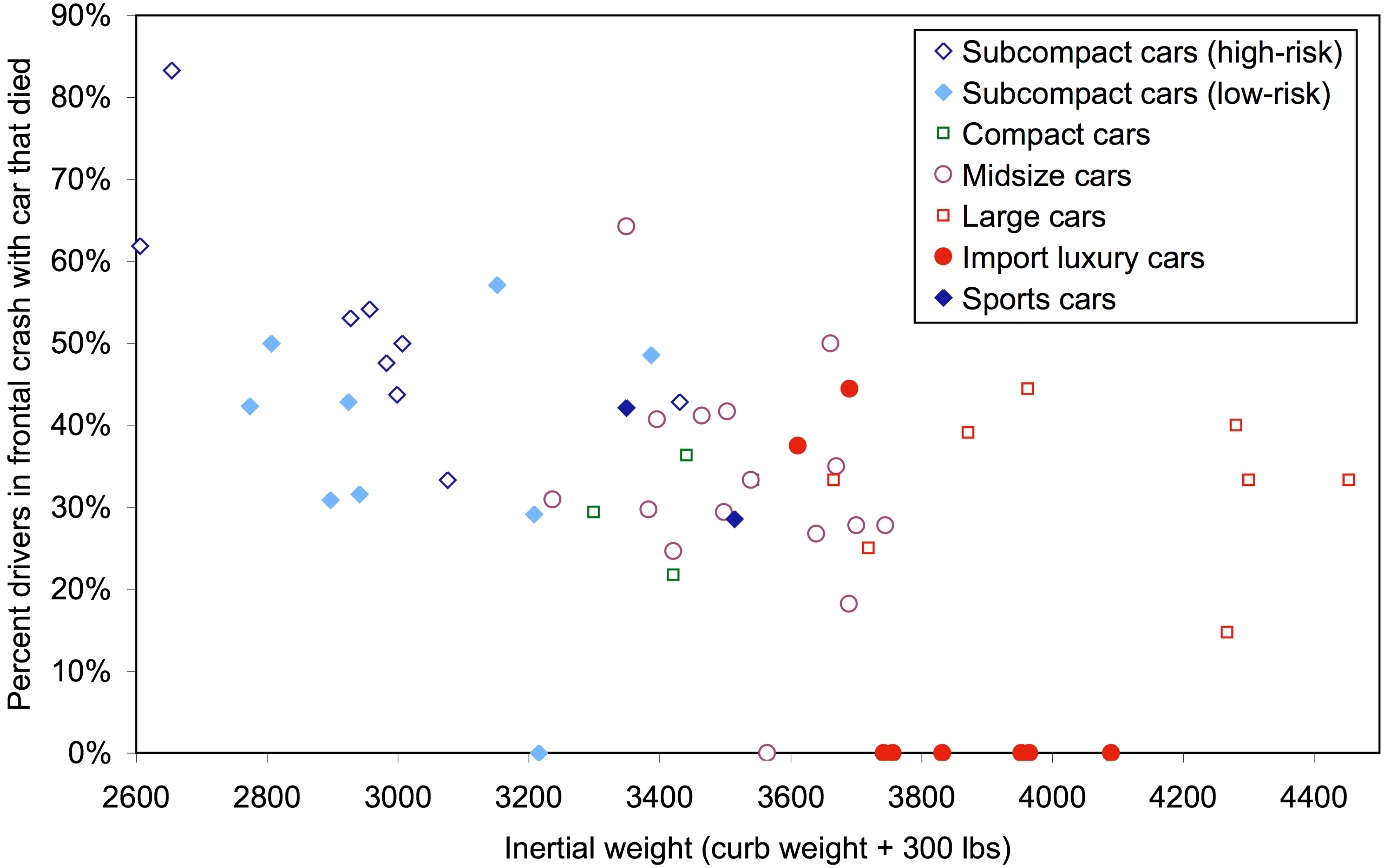
Strong relationship between car resale value and risk



Debunking the “simple physics” argument

- “It’s simple physics; all else being equal, you are safer in a heavier vehicle than in a lighter vehicle”
- All else is never equal; vehicle design is important
  - how well stiff structures in two vehicles are aligned
  - presence of safety equipment (airbags, new seatbelt technology, head rests)
  - presence of interior padding
- We analyzed fatality ratio (fraction of car drivers who died, in crashes with another car)
  - little relationship between fatalities in frontal crash with another car and car weight
- In car-light truck crash, aggressivity of truck is more important than weight of car
  - most serious injuries in car-light truck side impact crashes are due to truck intrusion into car, not deceleration

Weak relationship between fatalities in frontal crash with another car and car weight



Intrusion becoming a major source of serious injuries in certain crashes (Patel et al., 2006)

- Three general causes of serious injury in vehicles:
  - —contact with interior surfaces
  - —contact with intruded surfaces of other vehicle
  - —restrained deceleration
- Intrusion injuries are the result of structural incompatibility between vehicles, rather than weight differential
- Intrusion injuries are nearly twice as prevalent when cars have been struck in the side (61%) as when struck in the front (35%)
  - —intrusion causes 35% of serious injuries in a car when struck in the side by another car, but 58% when struck in the side by a light truck
- Further research to define “intrusion” in frontal crashes

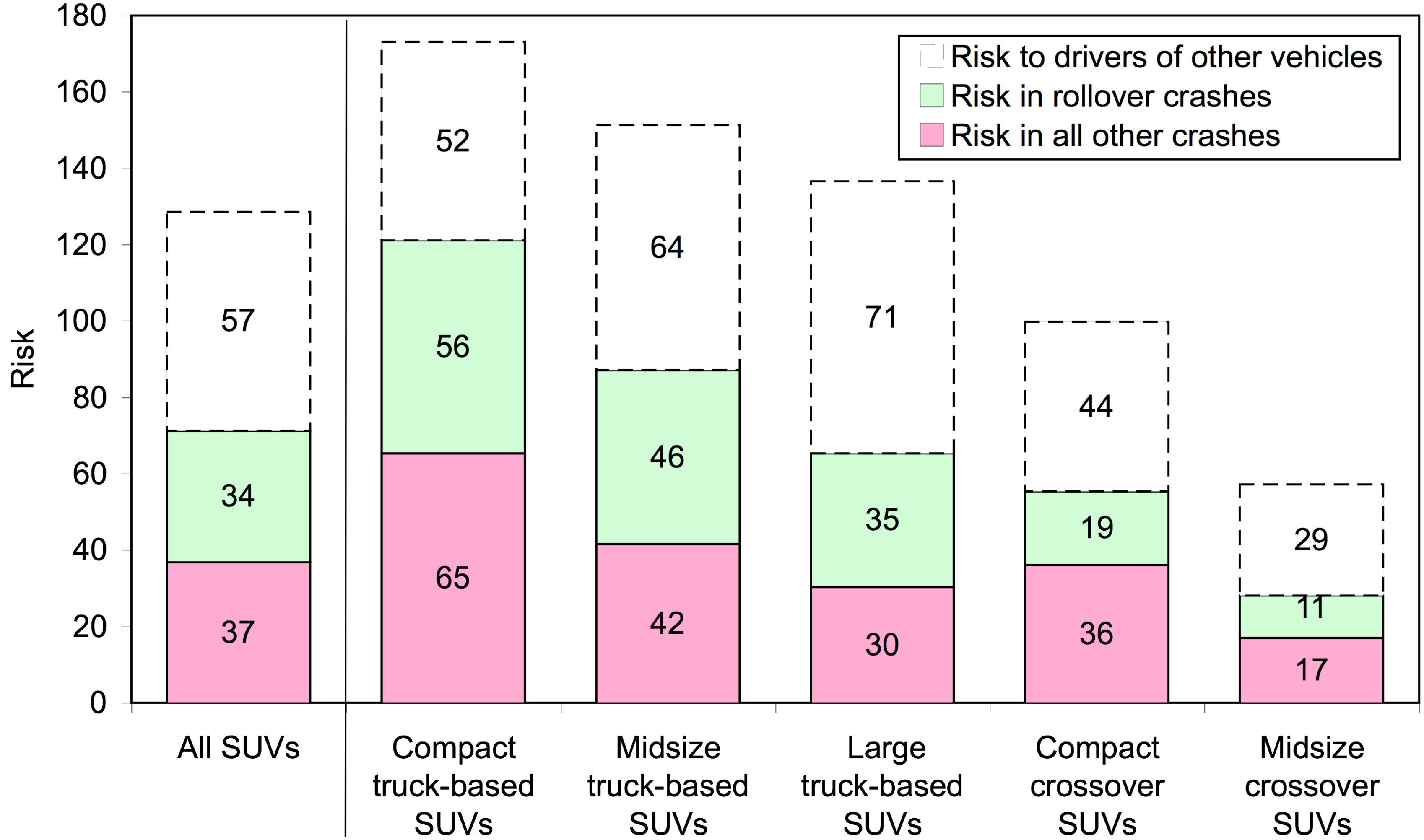
European researchers' agree

- "The results from this project have overturned the original views about [car-to-car] compatibility, which thought that mass and the mass ratio were the dominant factors." (Edwards et al., 2001)
- "The scientific community now agrees that mass does not play a direct role in [car-to-car] compatibility." (Delannoy et al., 2003)
- "Moreover, if mass appears to be the main parameter linked to aggressivity of cars [against other cars], it is because this is the easiest and universal parameter that is collected in all accident databases." (Faerber, 2001)
- There are very few light truck-car crashes in Europe; compatibility even more important in US than in Europe

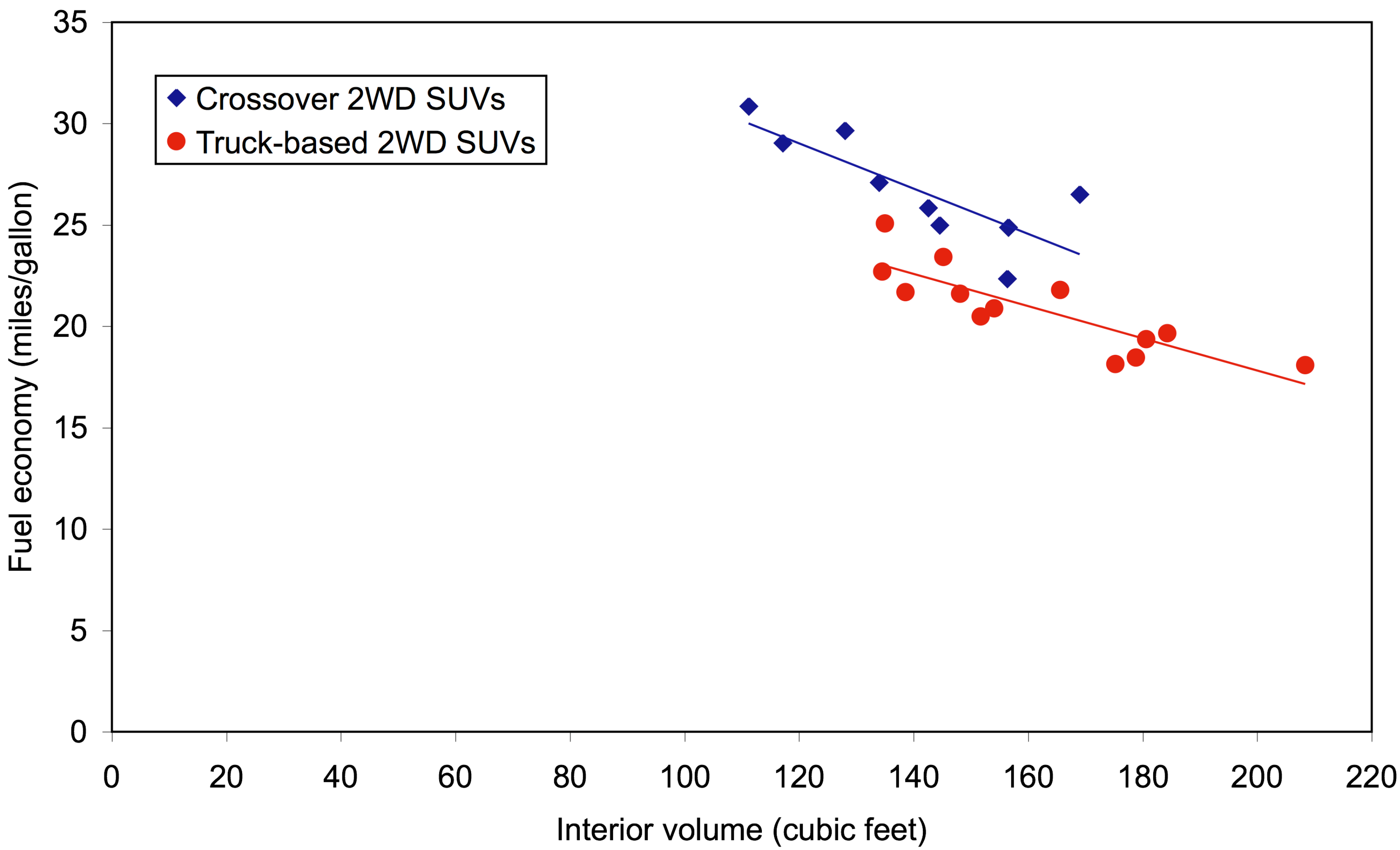
Are crossover SUVs a solution?

- Conventional SUVs built on pickup chassis, with high/stiff fronts (body-on-frame construction)
- Manufacturers now making "crossover" SUVs built on car-like, unit body chassis
- Crossover design lowers center of gravity (increases stability, reduces rollovers) and lowers/softens front (reduces aggressivity)
  - crossovers are safer, for both crossover drivers and others, than truck-based SUVs…
  - … and crossovers tend to have 17% higher fuel economy than truck-based SUVs with the same interior volume
- However crossover SUVs tend to have lower towing capacity than some truck-based SUVs

Crossover SUVs have lower risks than truck-based SUVs…



… and about 17% higher fuel economy for same interior volume (MY05)



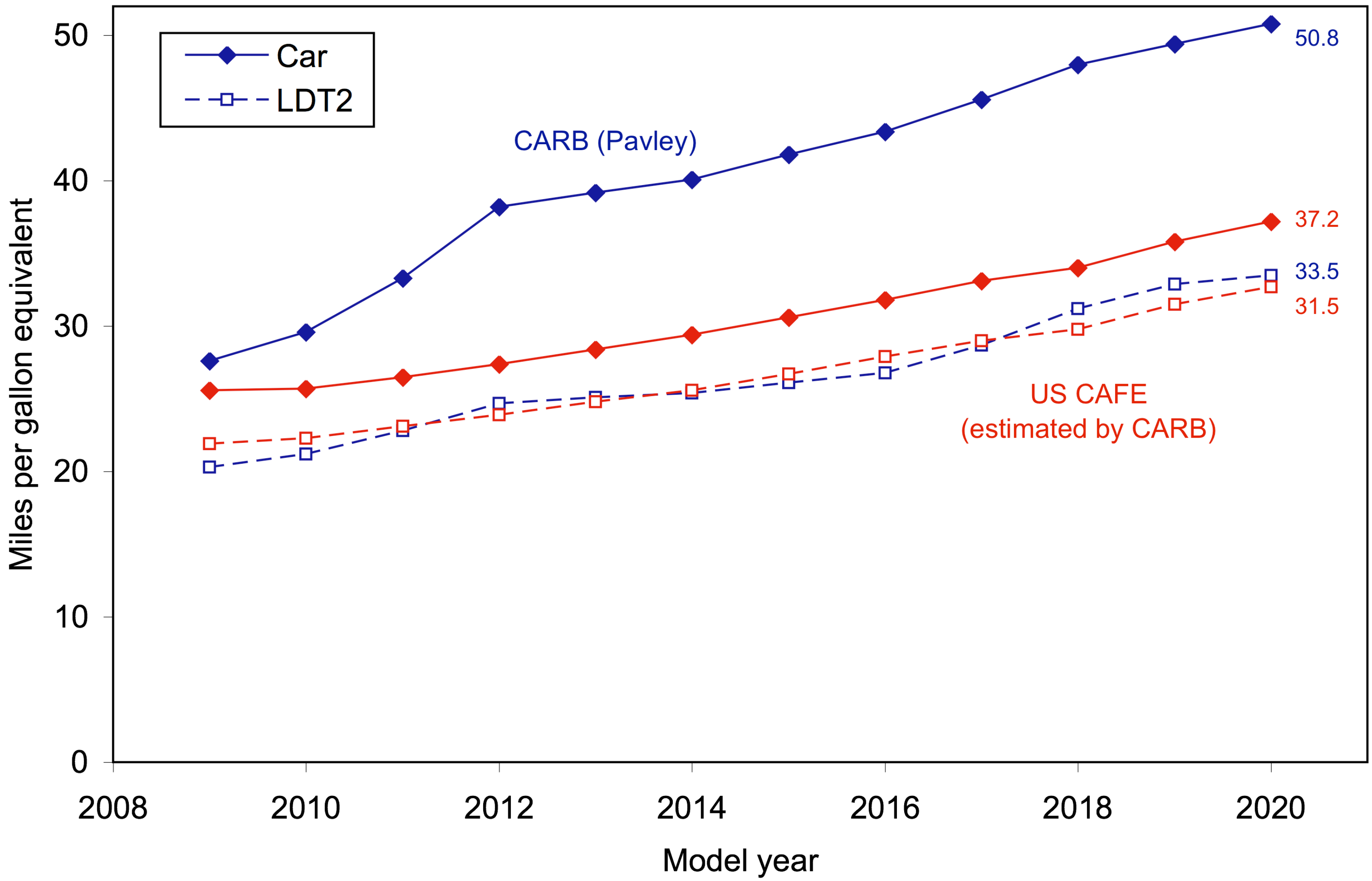
Light trucks are becoming safer

- Rollover risk in SUVs is declining
  - —due to increased numbers of safer crossovers, rather than improvements to truck-based SUVs
  - —truck-based SUVs and pickups still have much higher (2x) rollover risk than that of average car
- Increased use of Electronic Stability Control should dramatically reduce rollovers in all vehicles
- Risk that pickups impose on others is declining
  - —some claim this is from voluntary changes made by manufacturers to biggest pickups…
  - —…but risk to others is declining even for compact pickups and larger pickups that have not yet adopted voluntary changes
  - —risk reduction may be due to changes made to cars to make them more compatible with trucks
  - —even with improvement, the risk that pickups impose on others still much higher (2x to 5x) than that of average car

Going forward

- New standards
  - California AB1372 (Pavley);
    - regulates tailpipe CO_2 emissions, under Clean Air Act exemption
  - revised US CAFE standard
    - regulates fuel economy (miles per gallon)
- Both regulations continue light truck “loophole”
  - pickups and SUVs must meet a less stringent standard than cars
  - although CA treats smaller trucks, SUVs and minivans (LDT1) as cars
- Better approach would be to require all vehicles to meet same standard
  - this would dramatically raise price of heaviest pickups and SUVs
  - subsidize purchase of heavy pickups and SUVs for appropriate commercial uses through tax incentives
- Safety can be regulated directly, independently of fuel economy

Both California and US standards continue “loophole” for light trucks



Other resources

- LBNL reports
  - http://eetd.lbl.gov/EA/teepa/pub.html#Vehicle
- NHTSA crash tests (NCAP)
  - http://www.safecarguide.com/exp/usncap/usncap.htm
- NHTSA CAFE FAQ
  - http://www.nhtsa.dot.gov/cars/rules/cafe/overview.htm
- IIHS crash tests
  - http://www.iihs.org/ratings/default.aspx
- IIHS driver death rates
  - http://www.iihs.org/sr/pdfs/sr4204.pdf
- Public Citizen vehicle safety
  - http://www.citizen.org/autosafety/
- *High and Mighty: SUVs: The World's Most Dangerous Vehicles and How They Got that Way*, Keith Bradsher