# Searching for Hidden Costs: A Technology-Based Approach to the Energy Efficiency Gap in Light-Duty Vehicles

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# Agenda

- Policy Context
- Content Analysis
- Preliminary Results
- Summary/Conclusion

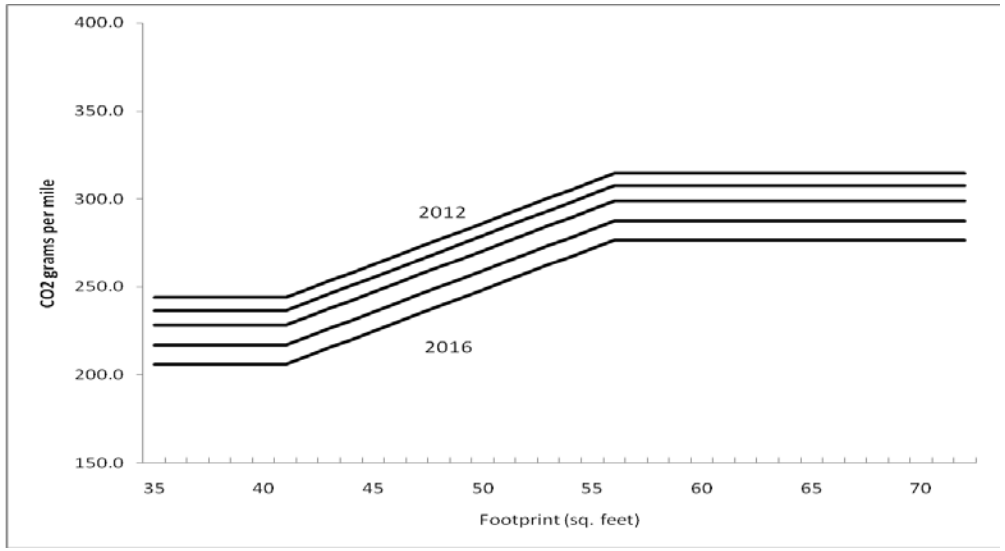
# Policy Context: EPA/NHTSA's Light Duty Greenhouse Gas-Fuel Economy Rule

- EPA has the responsibility to regulate air pollutants
  - *Massachusetts v. EPA* concluded that EPA could regulate GHG under the Clean Air Act
- National Highway Traffic Safety Administration (NHTSA, Dept. of Transportation) has the responsibility to regulate fuel economy of vehicles
- The primary way to reduce GHG emissions from vehicles is to improve fuel economy
- The rules are increasing fuel economy & reducing GHG emissions from MY 2012-2025 vehicles
  - MY 2012-16 standards issued in 2010
  - MY 2017-2025 standards issued in 2012
  - http://www.epa.gov/otaq/climate/regs-light-duty.htm

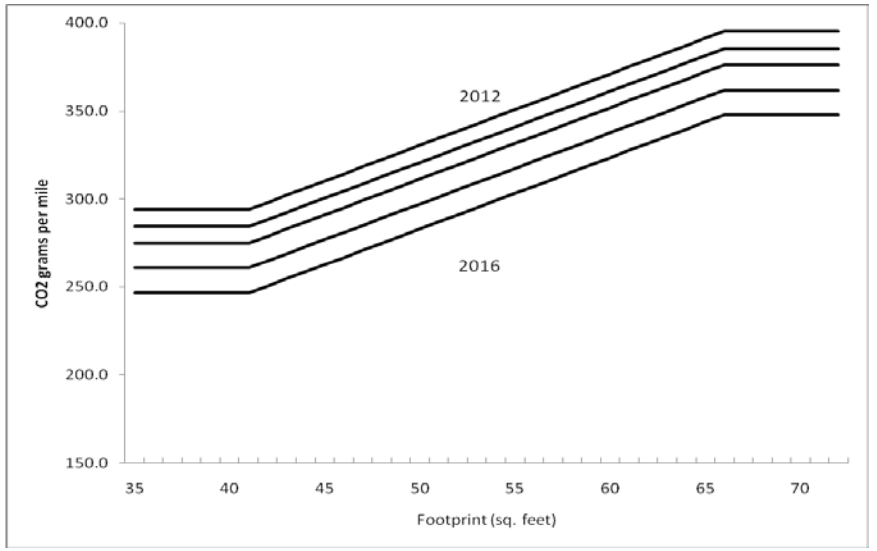
# MY 2012-16 EPA Standards

## Footprint standard in $CO_2$ (g/mi) space

Car




Truck




Source: Federal Register 75(88) (May 7, 2010): 25334-7

# Benefits predicted greatly to exceed costs, with largest benefits from fuel savings (MY 2012-16 standards; Millions of 2007 dollars)

| | 2020 | 2030 | 2040 | 2050 | NPV, 3% | NPV, 7% |
|---|---|---|---|---|---|---|
| Vehicle Compliance Costs | $15,600 | $15,800 | $17,400 | $19,000 | $345,900 | $191,900 |
| Fuel Savings | $35,700 | $79,800 | $119,300 | $171,200 | $1,545,600 | $672,600 |
| Reduced $CO_2$ Emissions at each assumed SCC value | | | | | | |
| Avg SCC at 5% | $900 | $2,700 | $4,600 | $7,200 | $34,500 | $34,500 |
| Avg SCC at 3% | $3,700 | $8,900 | $14,000 | $21,000 | $176,700 | $176,700 |
| Avg SCC at 2.5% | $5,800 | $14,000 | $21,000 | $30,000 | $299,600 | $299,600 |
| 95th percentile SCC@3% | $11,000 | $27,000 | $43,000 | $62,000 | $538,500 | $538,500 |
| Criteria Pollutant Benefits | na | $1,200-1,300 | $1,200-1,300 | $1,200-$1,300 | $21,000 | $14,000 |
| Energy Security Impacts (price shock) | $2,200 | $4,500 | $6,000 | $7,600 | $81,900 | $36,900 |
| Reduced Refueling | $2,400 | $4,800 | $6,300 | $8,000 | $87,900 | $40,100 |
| Value of Increased Driving | $4,200 | $8,800 | $13,000 | $18,400 | $171,500 | $75,500 |
| Accidents, Noise, Congestion | $2,300 | $4,600 | $6,100 | $7,800 | $84,800 | $38,600 |
| **Quantified Net Benefits at each assumed SCC value** | | | | | | |
| **Avg SCC at 5%** | **$27,500** | **$81,500** | **$127,000** | **$186,900** | **$1,511,700** | **$643,100** |
| **Avg SCC at 3%** | **$30,300** | **$87,700** | **$136,400** | **$200,700** | **$1,653,900** | **$785,300** |
| **Avg SCC at 2.5%** | **$32,400** | **$92,800** | **$143,400** | **$209,700** | **$1,776,800** | **$908,200** |
| **95th percentile SCC at 3%** | **$37,600** | **$105,800** | **$165,400** | **$241,700** | **$2,015,700** | **$1,147,100** |

"Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis." US EPA, EPA-420-R-10-009, April 2010, Chapter 8.4

# Is there an energy paradox/efficiency gap in the LD vehicle market?

- This analysis found many technologies that would improve vehicle fuel economy and save consumers money, that were not in common use
  - Consumers have an obvious interest in improved fuel economy
  - Automakers have an obvious interest in providing consumers what they want
  - Why didn't private markets provided these technologies?
- Possible reasons the paradox might not exist in reality:
  - The agencies overestimated the effectiveness of these technologies in reducing fuel consumption
  - The agencies underestimated the costs of these technologies
  - There might be "hidden costs" of the fuel-saving technologies
- The standards are in effect now
  - We can look at costs, effectiveness, hidden costs
- This study focuses on whether there are hidden costs of the technologies

# Method:  Content Analysis

- A method to analyze written material in order to make systematic, repeatable, and measurable inferences from texts
- It commonly involves
  - Searching for key words or ideas and coding them
    - e.g., mention of 6-speed transmissions
  - Making inferences about their meanings in context
    - e.g., are there problems with the transmission
  - Conducting quantitative analysis of the data
    - e.g., are 6-speed transmissions generally evaluated positively or negatively?

# Content analysis of auto reviews

- Auto reviews include qualitative assessments of vehicle technologies
- Auto reviewers are expected to have expertise in identifying vehicle qualities
  - They are professional evaluators, trained to identify positive and negative characteristics of vehicles
  - They are likely to be at least as sensitive to vehicle characteristics as average vehicle buyers

# Method: Identification of websites to include

- Keyword search on “new cars,” “buying a new car,” “auto reviews”
- Exclude websites without national, professional auto reviews
- Monthly unique views of websites to gauge popularity
  - Quantcast.com, Compete.com
  - Add websites considered similar by Compete.com
  - Exclude websites with less than one million unique views
- Reviews of MY 2014 vehicles
  - Available for sale in the U.S.
  - Subject to the LD vehicle GHG/fuel economy standards
  - With independent evaluation of vehicle quality after a test drive

# Websites used

| Website | Review Counts |
|---|---|
| automobilemag.com | 144 |
| autotrader.com | 225 |
| caranddriver.com | 218 |
| consumerreports.org | 88 |
| edmunds.com | 112 |
| motortrend.com | 221 |
| Total | 1008 |

# Coding

- Technologies, operational characteristics to be coded were developed from technologies identified as potentially contributing to achieving the standards, and professional engineering judgment
- EPA worked with an independent adjudicator to identify the technologies and interpret reviewer evaluations in sample reviews
- The adjudicator trained 2 coders who conducted the analysis
  - Inter-coder reliability tests were used to ensure quality and replicability
  - Inter-coder agreement > 90%
  - Cohen's Kappa, a statistical measure which takes into account the amount of agreement that could be expected to occur through chance:
    - 0.6 (fair agreement) after initial training
    - 0.8 (excellent agreement) with follow-up.

# What we coded: Efficiency technologies

| Feature Type | | Feature |
|---|---|---|
| Active Air Dam | | Active air dam |
| Active Grill Shutters | | Active grill shutters |
| Active Ride Height | | Active ride height |
| Electric Assist or Low Drag Brakes | | Electric assist or low drag brakes |
| Lighting - LED | | Lighting-LED |
| Low Rolling Resistance Tires | | Low rolling resistance tires |
| Mass Reduction | | Mass reduction |
| Passive Aerodynamics | | Passive aerodynamics |
| Powertrain | Engine | Cylinder deactivation |
| | | Diesel |
| | | Electronic power steering |
| | | Full electric |
| | | GDI |
| | | General Engine |
| | | Hybrid |
| | | Plug-in hybrid electric |
| | | Stop-start |
| | | Turbocharged |
| | General Powertrain | General Powertrain |
| | Transmission | CVT |
| | | DCT |
| | | General Transmission |
| | | High speed automatic |

# What we coded: Operational characteristics

| Feature Type | | Feature |
|---|---|---|
| Drivability | Handling | Steering feel/Controllability/Responsiveness |
| | | General Drivability |
| | | General handling |
| | Acceleration | Acceleration feel/Smoothness/Responsiveness |
| | | Acceleration capability/Power/Torque |
| | | General acceleration |
| | Braking | Brake feel/Responsiveness |
| | | Stopping ability |
| | | General Braking |
| Noise | | Tire/Road |
| | | Wind |
| | | Interior |
| | | Powertrain |
| | | General noise |
| Vibration | | Chassis |
| | | Powertrain |
| | | General vibration |
| Ride comfort | | Ride comfort |
| Fuel economy | | Fuel economy |
| Range | | Range |
| Charging | | Charging |

# Coding

- “Acceleration from the V6 is quiet and strong, with the 6-speed automatic transmission gliding smoothly through its gears. ”
  - Positive for high-speed automatic transmission
  - Positive for general engine
  - Positive for acceleration capability
  - Positive for powertrain noise

Technologies

Operational Characteristic

- “We like the effortless power and the smooth transmission, but the auto start/stop system has more delay than some, the throttle can be a bit on the jumpy side and the light steering is disconcerting. ”
  - Positive for high-speed automatic [transmission type noted elsewhere]
  - Negative for stop/start
  - Positive for acceleration capability
  - Negative for steering feel-controllability-responsiveness

Technologies

Operational Characteristic

# The Data

- MY 2014 light-duty vehicles
- 1008 reviews
- 16,294 codes
  - 3575 (about 22%) of the codes are about fuel-saving technologies
  - The remainder are about operational characteristics
- Results at the level of the codes include all mentions of each technology
  - E.g., 2 negative codes for a CVT = 2 negative codes for a CVT
- Results at the level of the reviews aggregate all mentions of a technology with multiple codes and the same evaluation to one
  - E.g., 2 negative codes for a CVT = 1 review-level negative code
  - E.g., 2 negative codes and 1 positive code for a CVT = 1 review-level negative code and 1 review-level positive code

# Auto reviews by make

| Make | Count | Market Share | Make | Count | Market Share | Make | Count | Market Share |
|---|---|---|---|---|---|---|---|---|
| Chevrolet | 85 | 12.2% | Honda | 34 | 8.4% | Land Rover | 15 | 0.3% |
| Mercedes | 74 | 2.2% | Porsche | 34 | 0.3% | Bentley | 11 | |
| BMW | 69 | 2.1% | Jaguar | 28 | 0.1% | Mini Cooper | 11 | 0.4% |
| Toyota | 63 | 12.2% | Buick | 27 | 1.3% | Rolls Royce | 9 | |
| Mazda | 49 | 1.9% | Infiniti | 25 | 0.8% | Fiat | 8 | 0.3% |
| Ford | 47 | 14.9% | Subaru | 25 | 3.0% | Ferrari | 7 | |
| Kia | 44 | 3.5% | Acura | 24 | 1.0% | Ram | 7 | 2.6% |
| Jeep | 42 | 3.9% | Dodge | 24 | 3.6% | Lincoln | 6 | 0.6% |
| Nissan | 40 | 7.6% | Lexus | 23 | 1.9% | Volvo | 5 | 0.3% |
| Audi | 37 | 1.1% | Hyundai | 19 | 4.5% | Chrysler | 4 | 1.8% |
| Volkswagen | 37 | 2.3% | GMC | 17 | 2.9% | Scion | 4 | 0.4% |
| Cadillac | 36 | 1.1% | Mitsubishi | 17 | 0.5% | Smart | 1 | 0.1% |

Reviews are not conducted in proportion to sales.

Market share data are Ward's sales figures for Sept. 2013 – Aug. 2014. Bentley, Rolls Royce, & Ferrari were not in those data.

# Technology results at level of auto review

If all references to a technology in a review have the same rating, it's counted once; if the references differ, one count per type of rating

## Efficiency Technology Review Count Totals

| Assessment | Total | Percent, All | Total, Excluding "General" | Percent, Excluding "General" |
|---|---|---|---|---|
| Positive | 1681 | 68% | 1047 | 68% |
| Neutral | 399 | 16% | 256 | 17% |
| Negative | 388 | 16% | 242 | 16% |
| Total | 2468 | 100% | 1545 | 100% |

More than 4 out of 5 comments about the technologies at the level of auto review were favorable or neutral.

Very similar results at code level

# Technology results at level of auto review

If all references to a technology in a review have the same rating, it's counted once; if the references differ, one count per type of rating

- For all technologies, positive ratings exceeded negative ratings
  - Most positively reviewed technologies by percentage
    - Active air dam — 100% of 6 reviews
    - Active grill shutters — 100% of 1 review
    - Mass reduction — 88% of 76 reviews
    - Cylinder deactivation — 86% of 35 reviews
    - LED lights — 85% of 20 reviews
    - GDI — 82% of 66 reviews
    - Turbocharging — 81% of 225 reviews
  - Most negatively reviewed technologies by percentage:
    - CVT — 32% of 114 reviews
    - Stop-start — 29% of 52 reviews
    - Low rolling resistance tires — 24% of 17 reviews
    - DCT — 23% of 70 reviews
    - Hybrid — 23% of 71 reviews
    - Electronic power steering — 22% of 210 reviews

Very similar results at code level

# Technology results at level of auto review

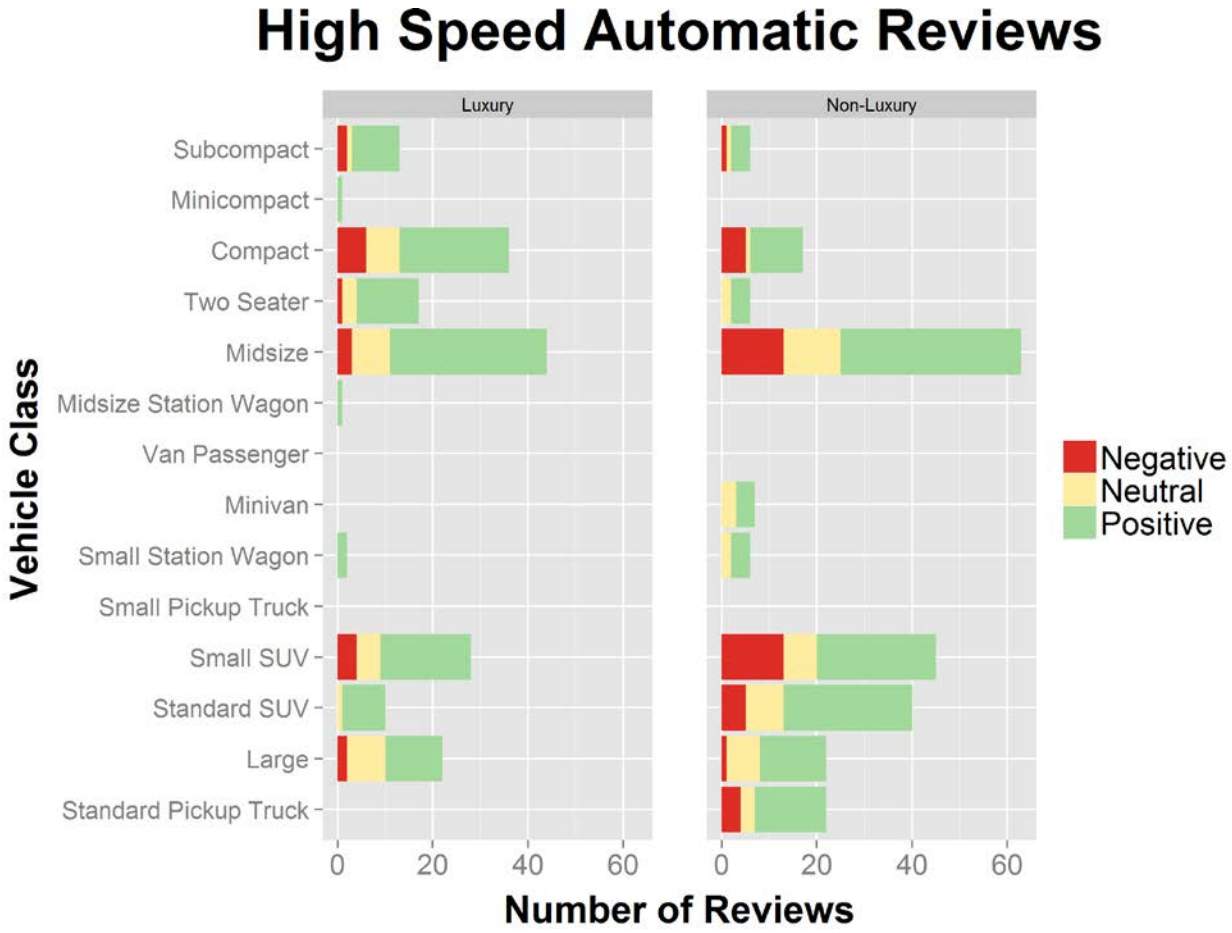
If all references to a technology in a review have the same rating, it's counted once; if the references differ, one count per type of rating

| Efficiency Technology Categories | | Coding level | Negative | | Neutral | | Positive | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Active Air Dam | | Active air dam | - | - | - | - | 6 | 100% | 6 |
| Active Grill Shutters | | Active grill shutters | - | - | - | - | 1 | 100% | 1 |
| Active Ride Height | | Active ride height | - | - | 1 | 33% | 2 | 67% | 3 |
| Electric Assist or Low Drag Brakes | | Electric assist or low drag brakes | 1 | 14% | 3 | 43% | 3 | 43% | 7 |
| Lighting - LED | | Lighting-LED | 1 | 5% | 2 | 10% | 17 | 85% | 20 |
| Low Rolling Resistance Tires | | Low rolling resistance tires | 4 | 24% | 5 | 29% | 8 | 47% | 17 |
| Mass Reduction | | Mass reduction | - | - | 9 | 12% | 67 | 88% | 76 |
| Passive Aerodynamics | | Passive aerodynamics | 4 | 10% | 7 | 18% | 29 | 73% | 40 |
| Powertrain | Engine | Cylinder deactivation | 1 | 3% | 4 | 11% | 30 | 86% | 35 |
| | | Diesel | 9 | 13% | 11 | 16% | 49 | 71% | 69 |
| | | Electronic power steering | 47 | 22% | 42 | 20% | 121 | 58% | 210 |
| | | Full electric | 2 | 9% | 6 | 27% | 14 | 64% | 22 |
| | | GDI | 6 | 9% | 6 | 9% | 54 | 82% | 66 |
| | | General Engine | 105 | 16% | 95 | 15% | 444 | 69% | 644 |
| | | Hybrid | 16 | 23% | 10 | 14% | 45 | 63% | 71 |
| | | Plug-in hybrid electric | 4 | 14% | 6 | 21% | 18 | 64% | 28 |
| | | Stop-start | 15 | 29% | 8 | 15% | 29 | 56% | 52 |
| | | Turbocharged | 20 | 9% | 23 | 10% | 182 | 81% | 225 |
| | General Powertrain | General Powertrain | 9 | 8% | 19 | 18% | 79 | 74% | 107 |
| | Transmission | CVT | 36 | 32% | 21 | 18% | 57 | 50% | 114 |
| | | DCT | 16 | 23% | 12 | 17% | 42 | 60% | 70 |
| | | General Transmission | 32 | 19% | 29 | 17% | 111 | 65% | 172 |
| | | High speed automatic | 60 | 15% | 80 | 19% | 273 | 66% | 413 |
| | | **Total** | 388 | 16% | 399 | 16% | 1,681 | 68% | 2,468 |

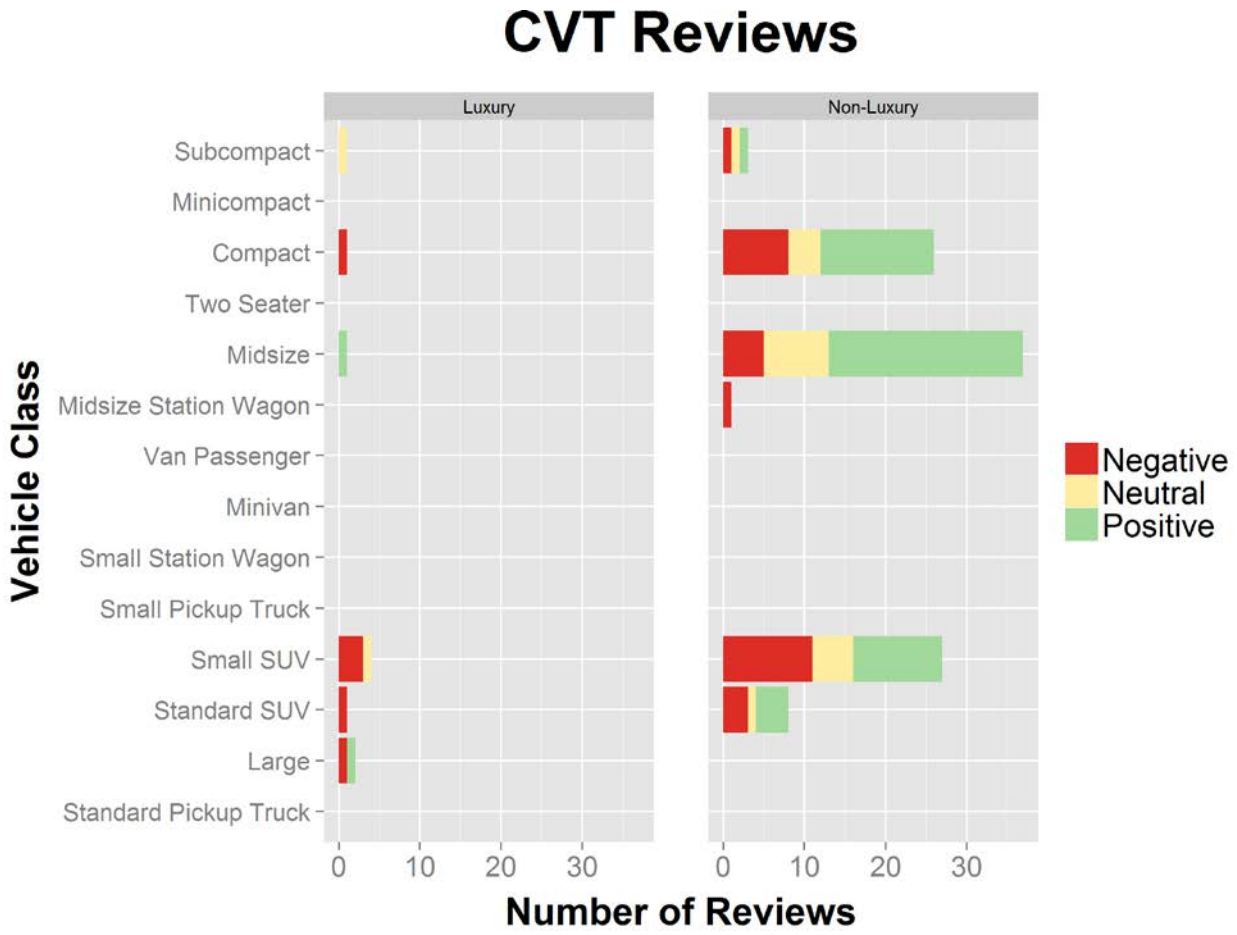
# Starting to dig into results

- Focus on vehicle class rather than manufacturer
  - Some technologies may be better suited to certain sizes or uses
  - Any manufacturer effects are unlikely to represent something inherent about the technology
    - If one manufacturer has trouble with one technology, it is likely to learn from other manufacturers
- Distinction between luxury and non-luxury vehicles
  - In some anecdotes, automakers roll out new technologies in luxury vehicles before they appear in standard vehicles
  - Acura, Audi, Bentley, BMW, Cadillac, Ferrari, Infiniti, Jaguar, Land Rover, Lexus, Lincoln, Mercedes, Porsche, Rolls Royce, and Volvo.
  - 403 of the 1008 reviews

# High-speed automatic transmissions: an example of primarily positive reviews across classes



# CVTs: the technology with the highest proportion of negative reviews (~1/3); 50% positive




Perhaps non-luxury manufacturers are doing better with CVTs than luxury manufacturers?

# Stop-start: Second-highest proportion of negative reviews, but still 71% positive/neutral

# Further exploration: Linear Probability Model

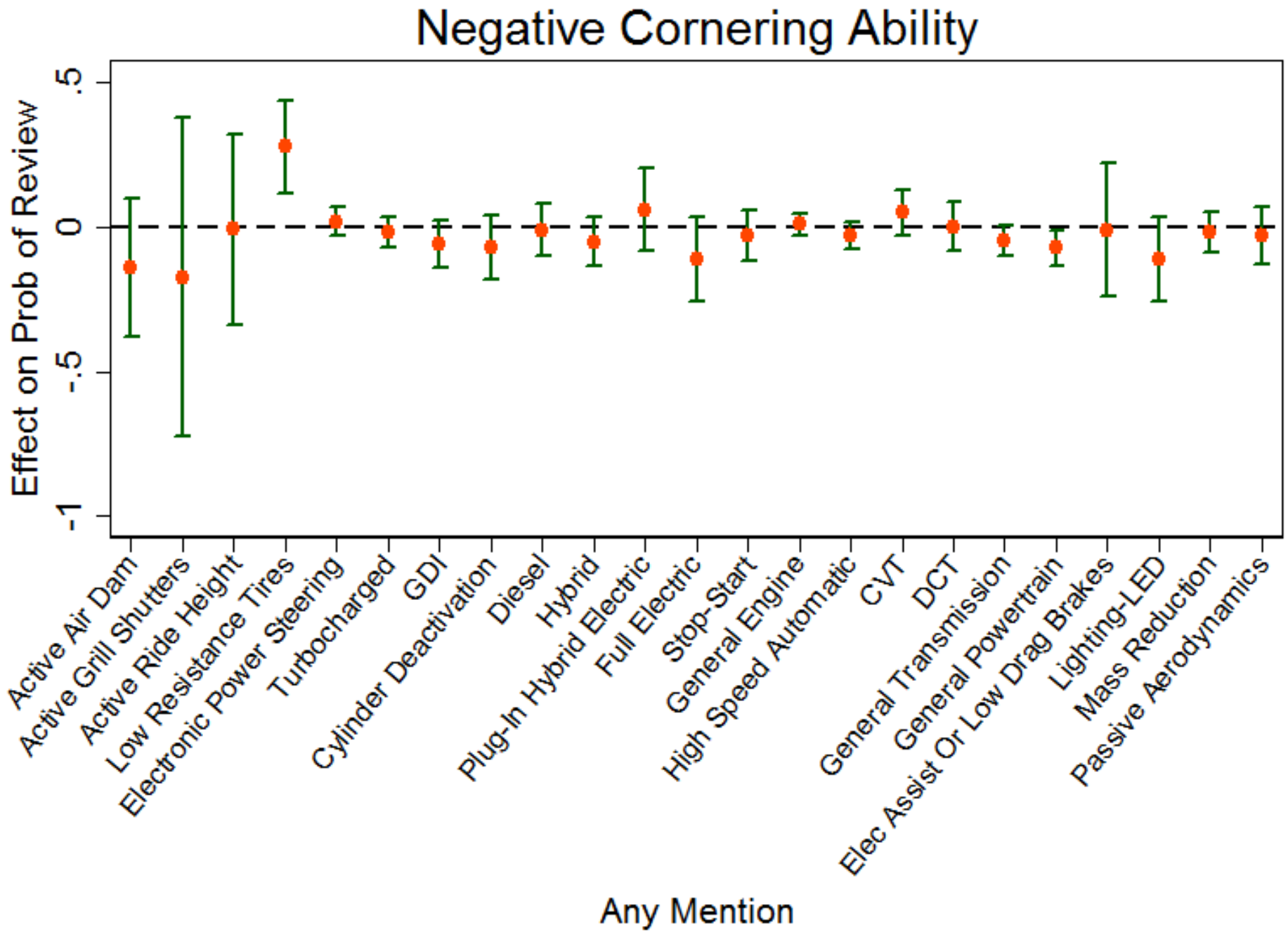
- Use linear regression to estimate the effects of each coded efficiency technology on the probability of a negative review for each operational characteristic *j*.
- Assumption that mention of a technology is equivalent to the vehicle having the technology

$$P\left(NegReview_{i,j}\right) = \sum_{k} \beta_k \, 1\left(ReviewTech_{i,k}\right) + m_i + w_i + \epsilon_{i,j}$$

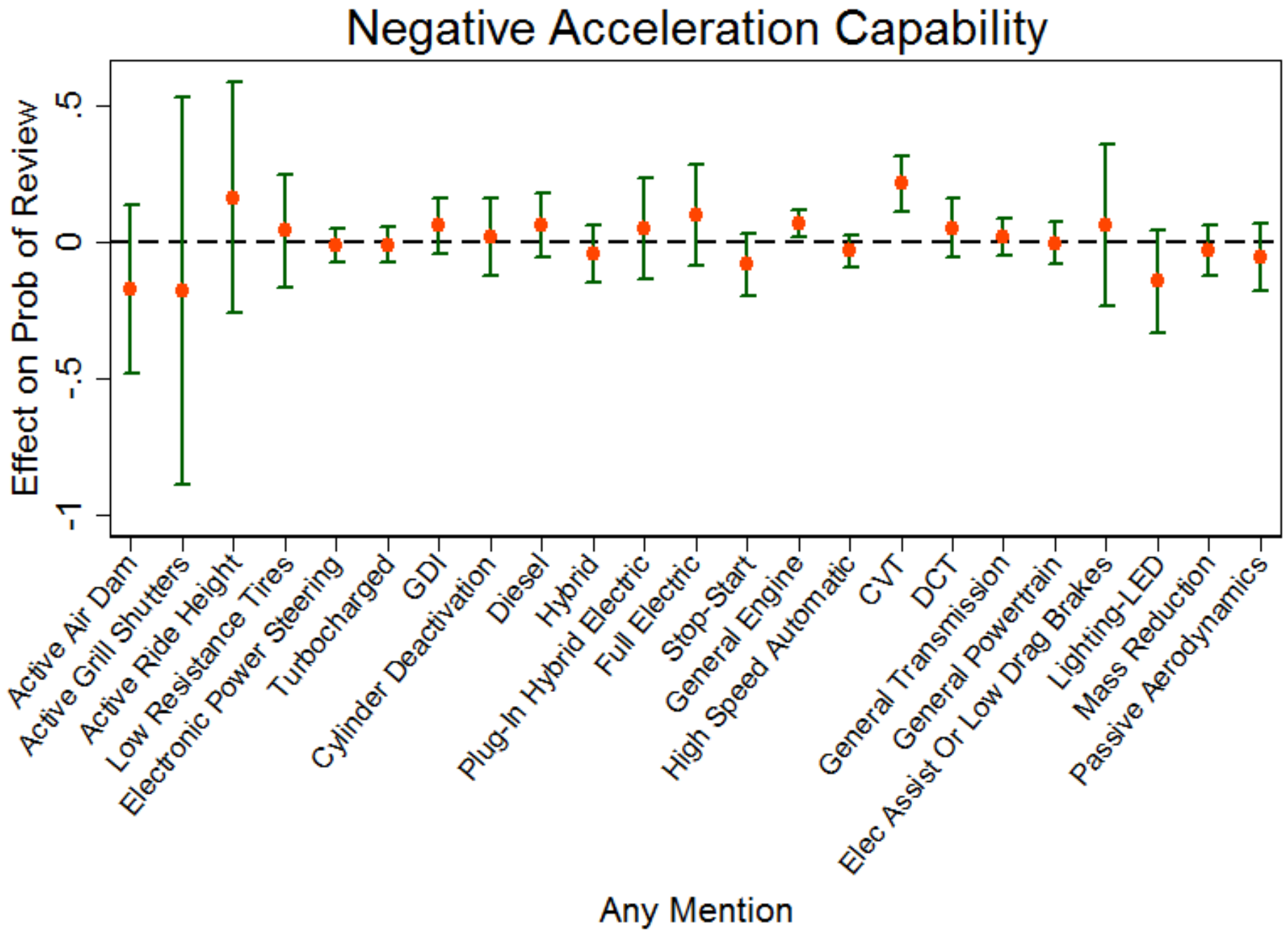
$m_i$ - Vehicle Make Fixed Effects
$w_i$ - Website Fixed Effects

- Note: Standard errors may be underestimated

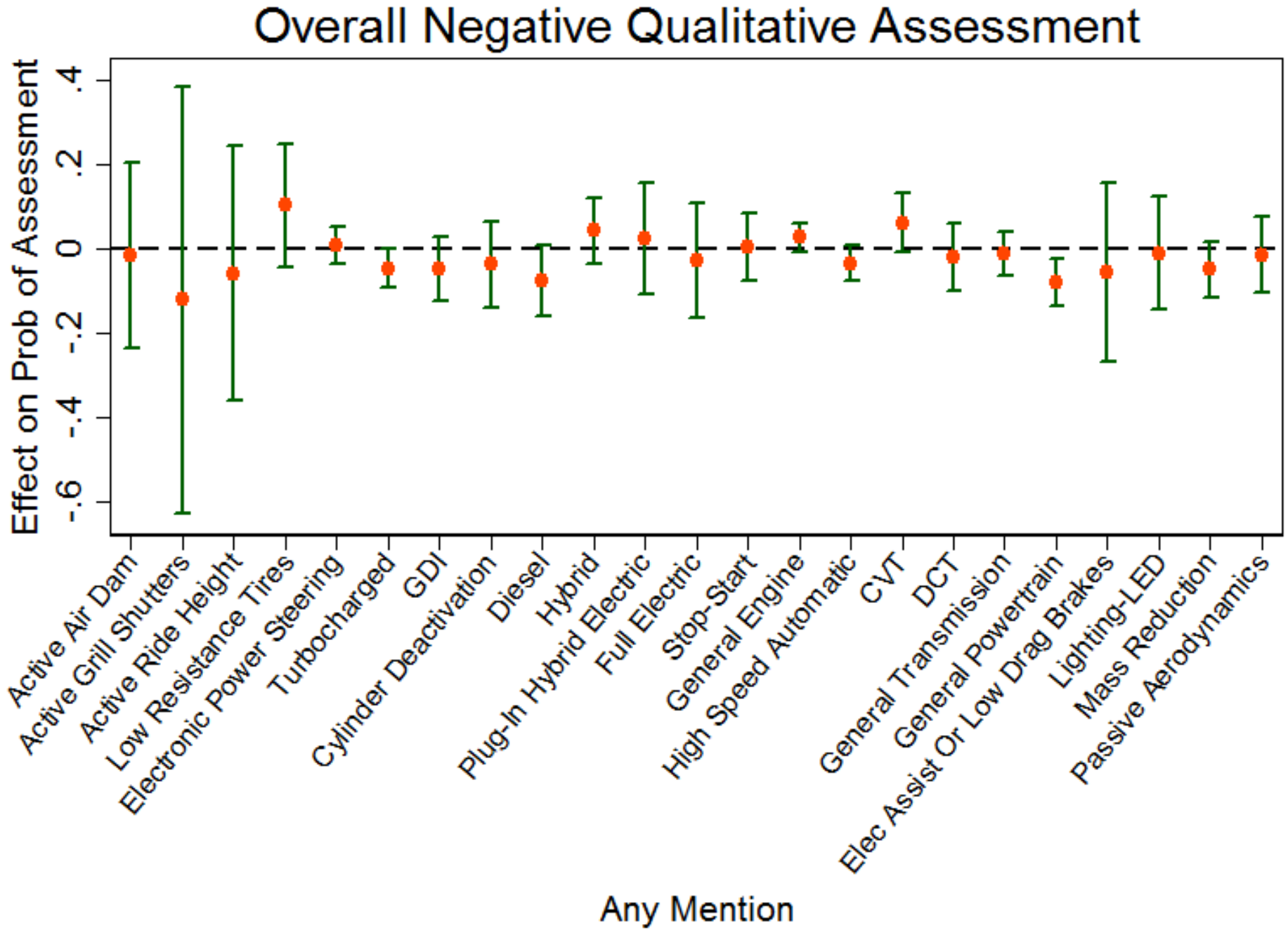
Real or chance effect of LRR tires?



Maybe an indication of the source of negative CVT responses?



At a first pass, no one technology seems to be associated with an overall negative assessment



# Some limitations of this work

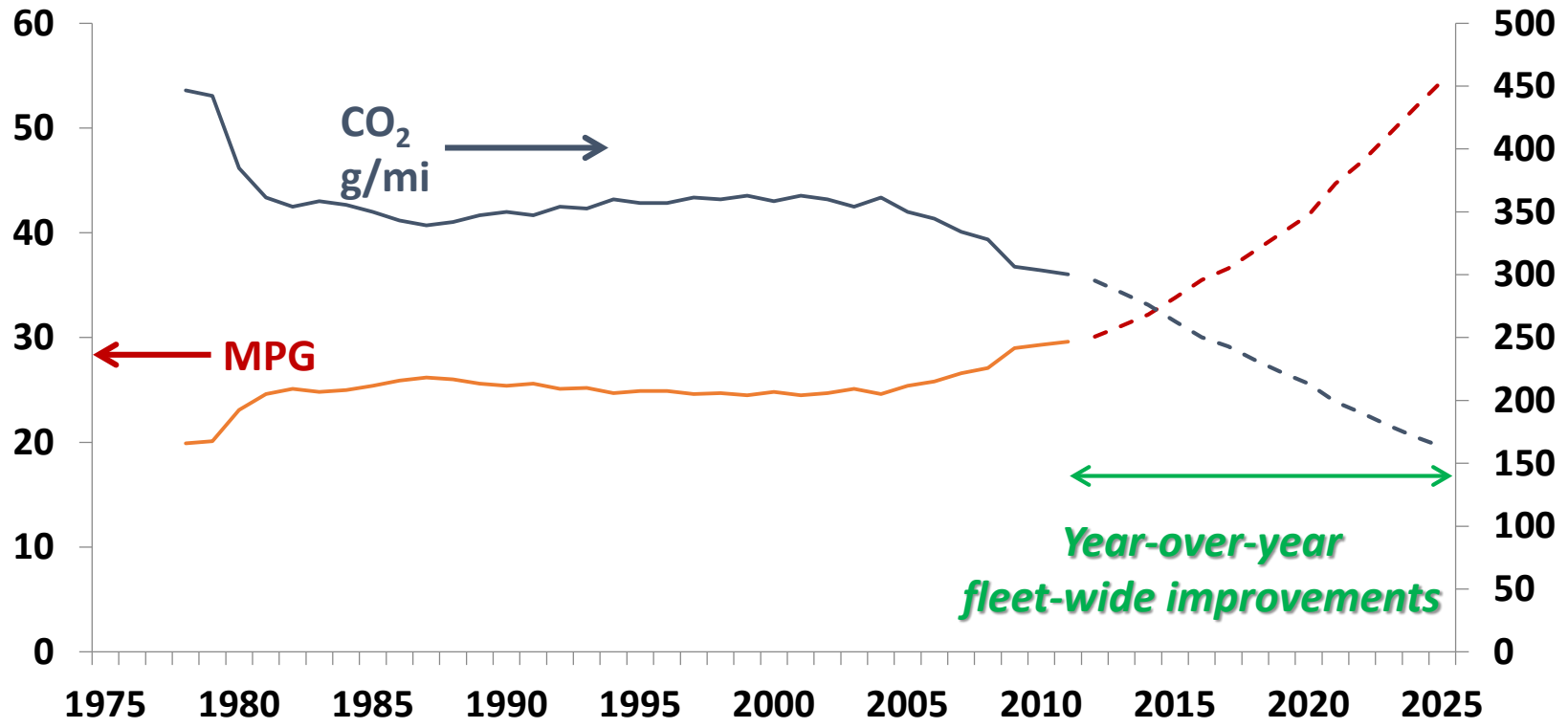
- Vehicles reviewed are not proportional to vehicles sold
  - This is not a random sample of all new vehicles sold, or of the vehicles with these technologies
  - The technologies are of primary interest, and all are covered
- There is some inherent subjectivity in the coding
  - We believe, though, that auto reviewers are not trying to trick anyone in their evaluations of the technologies
- How reviewers evaluate vehicles may not correspond to how vehicle owners respond to the technologies
  - We suspect that auto reviewers are generally harder to please, and more likely to notice, than the general public
  - Vehicle owners will spend more time with their autos than reviewers
- The reviews will not capture longer-term issues, such as reliability or maintenance

# A few takeaways so far

- Content analysis of professional auto reviews suggests automakers are implementing fuel-saving technologies without any systematic hidden costs
  - For all technologies, positive/neutral reviews exceed negative reviews
  - Positive/neutral reviews outnumber negative reviews, on average, 4+:1.
  - If some manufacturers or classes do worse than others, this is likely to be a temporary problem
  - Presence of the technologies in reviews does not seem to explain negative summary reviews for a vehicle
- Hidden costs appear not to be an explanation of the energy paradox in light-duty vehicles

# Appendix

# GHG/FE Standards 1978-2025




(2 cycle compliance: CAFE 1978-2011, GHG 2012-2025)

# Technology results at level of codes

Efficiency Technology Code Count Totals

| Assessment | Total | Percent | Total, Excluding "General | Percent, Excluding "General" |
|---|---|---|---|---|
| Positive | 2526 | 71% | 1556 | 70% |
| Neutral | 465 | 13% | 303 | 14% |
| Negative | 585 | 16% | 366 | 16% |
| Total | 3576 | 100% | 2225 | 100% |

More than 4 out of 5 comments about the technologies at the level of auto review were favorable or neutral.

# Technology results at level of codes

- For all technologies, positive codes exceed negative codes.
  - Most positively reviewed technologies by percentage
    - Active air dam — 100% of 6 codes
    - Active grill shutters — 100% of 1 code
    - Cylinder deactivation — 88% of 40 codes
    - Mass reduction — 87% of 94 codes
    - LED lights — 87% of 23 codes
    - Turbocharging — 86% of 335 codes
    - Diesel — 83% of 163 codes
    - GDI — 82% of 77 codes
  - Most negatively reviewed technologies by percentage:
    - CVT — 31% of 187 codes
    - Stop-start — 28% of 57 codes
    - DCT — 25% of 108 codes
    - Electronic power steering — 24% of 225 codes
    - Low rolling resistance tires — 24% of 17 codes

No notable differences between reviews and codes for most and least positively reviewed.

# Technology results at level of codes

| Efficiency Technology Categories | | Coding level | Negative | | Neutral | | Positive | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Active Air Dam | | Active air dam | - | - | - | - | 6 | 100% | 6 |
| Active Grill Shutters | | Active grill shutters | - | - | - | - | 1 | 100% | 1 |
| Active Ride Height | | Active ride height | - | - | 1 | 33% | 2 | 67% | 3 |
| Electric Assist or Low Drag Brakes | | Electric assist or low drag brakes | 1 | 13% | 3 | 38% | 4 | 50% | 8 |
| Lighting - LED | | Lighting-LED | 1 | 4% | 2 | 9% | 20 | 87% | 23 |
| Low Rolling Resistance Tires | | Low rolling resistance tires | 4 | 24% | 5 | 29% | 8 | 47% | 17 |
| Mass Reduction | | Mass reduction | - | - | 12 | 13% | 82 | 87% | 94 |
| Passive Aerodynamics | | Passive aerodynamics | 4 | 10% | 7 | 17% | 30 | 73% | 41 |
| Powertrain | Engine | Cylinder deactivation | 1 | 3% | 4 | 10% | 35 | 88% | 40 |
| | | Diesel | 15 | 9% | 13 | 8% | 135 | 83% | 163 |
| | | Electronic power steering | 53 | 24% | 43 | 19% | 129 | 57% | 225 |
| | | Full electric | 4 | 11% | 7 | 20% | 24 | 69% | 35 |
| | | GDI | 7 | 9% | 7 | 9% | 63 | 82% | 77 |
| | | General Engine | 156 | 15% | 112 | 11% | 741 | 73% | 1,009 |
| | | Hybrid | 28 | 19% | 13 | 9% | 104 | 72% | 145 |
| | | Plug-in hybrid electric | 7 | 13% | 6 | 11% | 42 | 76% | 55 |
| | | Stop-start | 16 | 28% | 9 | 16% | 32 | 56% | 57 |
| | | Turbocharged | 23 | 7% | 25 | 7% | 287 | 86% | 335 |
| | General Powertrain | General Powertrain | 14 | 11% | 19 | 15% | 91 | 73% | 124 |
| | Transmission | CVT | 58 | 31% | 32 | 17% | 97 | 52% | 187 |
| | | DCT | 27 | 25% | 14 | 13% | 67 | 62% | 108 |
| | | General Transmission | 49 | 22% | 31 | 14% | 138 | 63% | 218 |
| | | High speed automatic | 117 | 19% | 100 | 17% | 388 | 64% | 605 |
| | | **Total** | 585 | 16% | 465 | 13% | 2,526 | 71% | 3,576 |