Power and Fuel Economy Tradeoffs, and Implications for Benefits and Costs of Vehicle Greenhouse Gas Regulations

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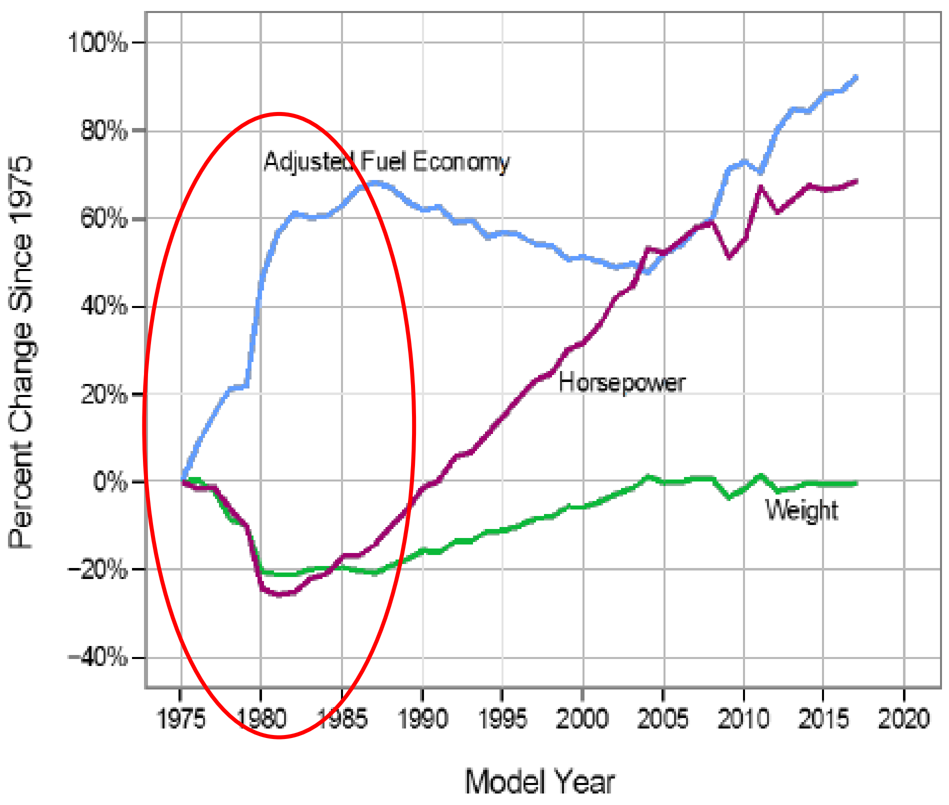
Potential for tradeoffs with other attributes

- When CAFE standards began in the late 1970s, vehicles became smaller and less powerful for a while.
- With tighter standards, might other vehicle attributes suffer?
- Would the public respond negatively to vehicles subject to the standards, if there are impacts on other vehicle characteristics?

Change in Adjusted Fuel Economy, Weight, and Horsepower Since 1975



EPA 2018. ”Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report,” p. 7.

Are times different?

- Vehicle greenhouse gas and fuel economy standards have been tightening annually since Model Year 2012
- Standards are now based on vehicles' footprints
    - Larger vehicles meet more lax standards than smaller vehicles
    - Reduced incentive to downsize vehicles
- Technology has been improving over time
    - Resulting in increases in performance and other improvements
- Will GHG reductions/fuel economy increases result in reduced performance relative to absence of the standards?

Relevance for BCA and policy analysis

- What is the appropriate without-standards reference case?
  - Would performance keep increasing, as in the past?
- Will GHG reductions/fuel economy increases result in reductions in performance, as in the late 1970s?
  - Are tradeoffs between performance and fuel economy physical laws of nature?
  - How does innovation affect this relationship?
  - Might there be ancillary benefits as well?
- If
  - Performance would have increased in the absence of the standards
  - Tradeoffs are unavoidable
- Then foregone power is a potential opportunity cost of the standards
  - And should be accounted for in the BCA

Existing studies

- Existing studies typically assume a constant elasticity between horsepower and fuel economy
  - Knittel (2011), Klier & Linn (2012, 2016), MacKenzie & Heywood (2015), Wang (2016)
  - The curve shifts over time due to innovation
- Standards may stimulate innovation
  - Porter hypothesis
  - If so, it is possible that standards may lead to net gains in both performance and fuel economy

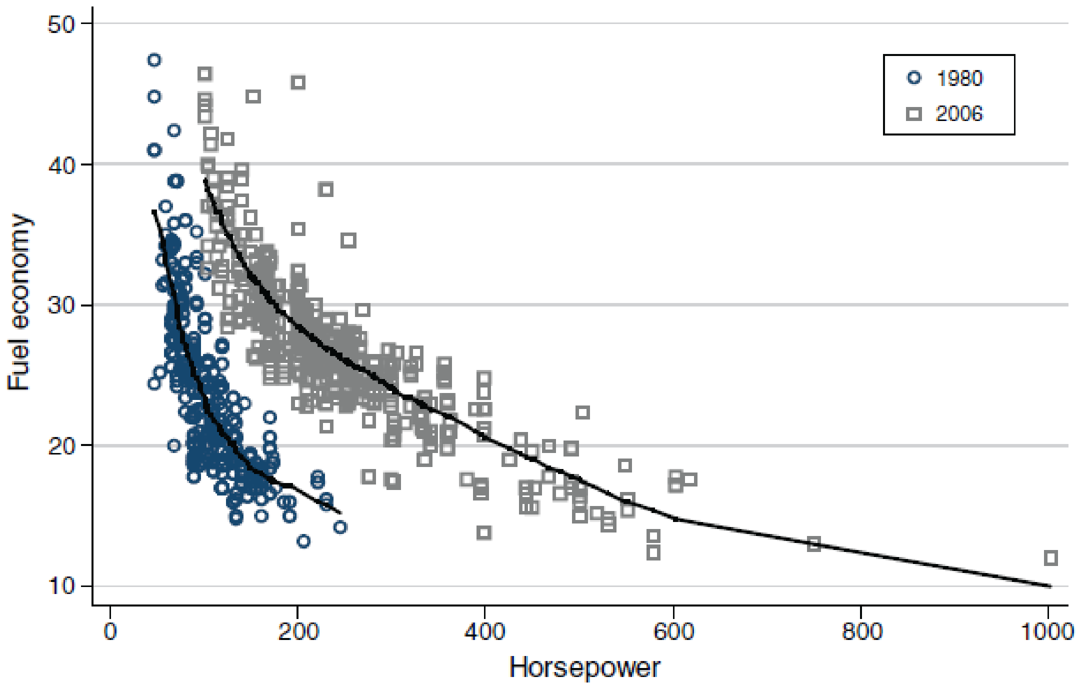


FIGURE 4. FUEL ECONOMY VERSUS HORSEPOWER, 1980 AND 2006, PASSENGER CARS

Knittel (2011), "Autos on Steroids," American Economic Review 101, p. 3379.

The typical regression

- Ln (Fuel economy) = $\beta_0 + \beta_1$ *Ln(Horsepower) + β_2 *Ln(Weight) + $\beta_{3a,b,etc}$ *Year Fixed Effects + $\beta_{4a,b,etc}$ *maybe a technology or two
  - β_1, β_2 measure the elasticities of Horsepower (HP) and Weight (WT) for Fuel economy (FE)
    - These are claimed to be technological relationships
  - β_{3+} measure the effects of innovation
    - Potentially affected by regulatory policy
- Data come from observations on vehicles produced
  - Top-down approach

Some concerns with this approach

- The data are not a random sample of all possible combinations of power & fuel economy
  - Only vehicles produced
    - Mix of vintages
  - Potentially not an accurate estimate of technological relationships
- Units of measurement matter
  - Do people care about horsepower (HP), or acceleration (e.g., 0-60 time)?
  - If the relationship between HP & 0-60 time is not constant, measuring HP may lead to biased results
    - Both for the performance-fuel economy tradeoff and for estimating innovation rates
    - E.g., if it's possible to get more acceleration from constant HP, then focusing on HP misses an innovation pathway.
- Variables in the regression affect the coefficient values
  - Including a technology in the regression separates its effect out of the effects of performance, weight, or innovation

This study

- We use a “bottom-up” approach to avoid these issues
  - Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) tool is a full-vehicle simulation model
  - We “sweep” the relationship between power and fuel economy for a standard sedan
  - This avoids sample-selection issues, by holding constant as much as possible
  - Results are specific for that vehicle type, but the pattern is likely to be more general
- Variations in the sweep:
  - 5 different model-years, reflecting different technology vintages
    - 1980, 2007, 2013, 2016, 2025 projected
  - Different ways of measuring key variables
    - Performance: HP or 0-60 acceleration time
    - Fuel economy: “official” MPG, or US06 mpg, meant to represent aggressive driving
- We then run a series of regressions of performance on fuel economy
  - As with existing research, using a constant elasticity and dummies for time period
  - Allowing the elasticities to vary as well as the intercepts

The “car” used – midsized sedan (e.g., Camry)

	Average HP/Wt (Min-Max)	Weight	Average HP (Min-Max)	Average 0-60 (Min-Max)	CFR MPG (Min-Max)	US06 MPG (Min-Max)
1980	0.032 (0.027 – 0.037)	3625	116 (96 – 134)	14.5 (12.3 – 17.2)	22.7 (20.6 – 24.8)	21.6 (20.8 – 22.4)
2007	0.050 (0.042 – 0.059)	3625	183 (151 – 215)	7.7 (6.6 – 9.2)	30.2 (28.0 – 32.4)	25.6 (25.0 – 26.1)
2013	0.053 (0.043 – 0.063)	3625	191 (154 – 228)	7.2 (6.1 – 8.8)	34.6 (32.2 – 36.9)	27.0 (26.1 – 27.6)
2016	0.056 (0.042 – 0.073)	3625	191 (154 – 228)	7.3 (6.3 – 8.8)	40.4 (37.0 – 43.2)	30.9 (30.1 – 31.1)
2025	0.050 (0.043 – 0.057)	3625	181 (154 – 208)	6.9 (6.1 – 7.8)	45.1 (43.8 – 46.3)	30.9 (30.7 – 31.2)

Weight held constant to hold as much as possible constant other than power & fuel economy

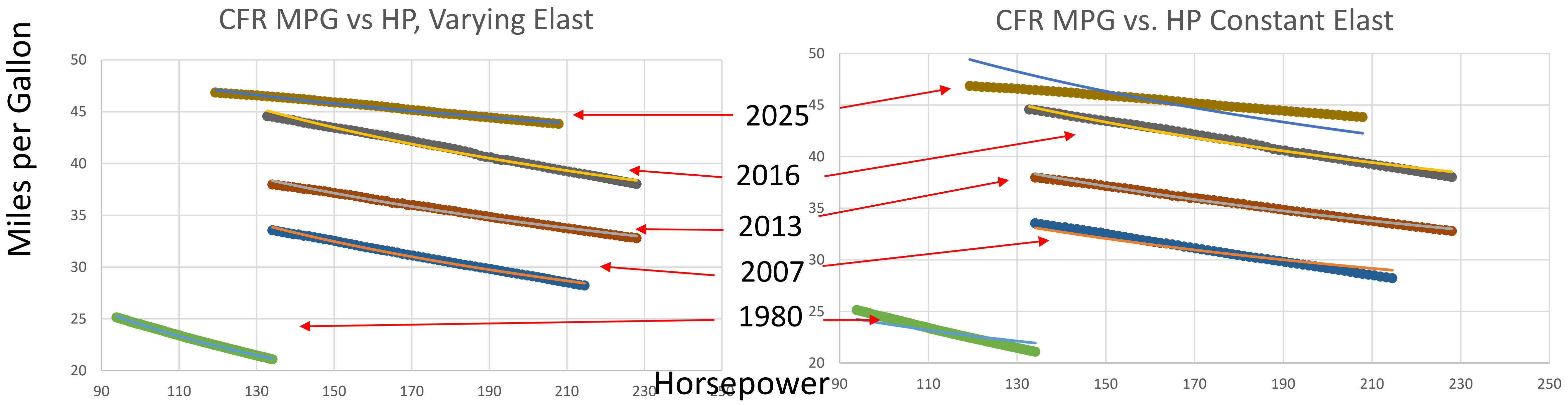
CFR MPG: combined unadjusted fuel economy, used for compliance but not for fuel economy label

US06 MPG: a drive cycle meant to better represent fuel economy during more aggressive driving

How our regression differs

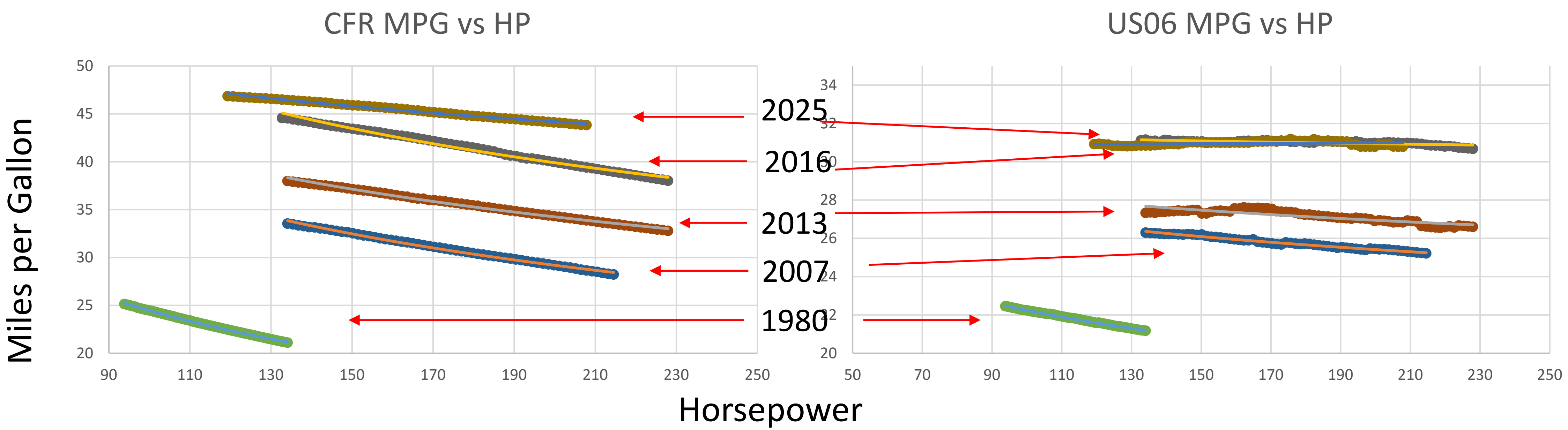
- Implications of constant weight
  - Because weight (WT) is constant, it is not included in the regressions
  - There is little difference in results using horsepower (HP) and results using 0-60 time
    - In engineering terms, HP/WT and 0-60 acceleration time (0-60) are closely correlated
    - HP and 0-60 are typically less closely correlated
    - But, because WT is constant here, HP and 0-60 end up closely correlated too
- We allow the power-fuel economy elasticities to vary over time
- No technology fixed effects
- We use 2 measures of FE: CFR MPG and US06 MPG
- Ln (Fuel economy) = $\beta_0 + \beta_1$ Ln(Horsepower or 0-60 time) ~~+ β_2 Ln(Weight)~~ + $\beta_{3a,b,etc}$ * Year Fixed Effects ~~+ maybe a technology or two~~ + $\beta_{4a,b,etc}$ * Ln(Horsepower) * Year Fixed Effects

CFR MPG, Varying vs. Constant Fuel Economy-Performance Elasticity (Lines are regression, dots are raw data)



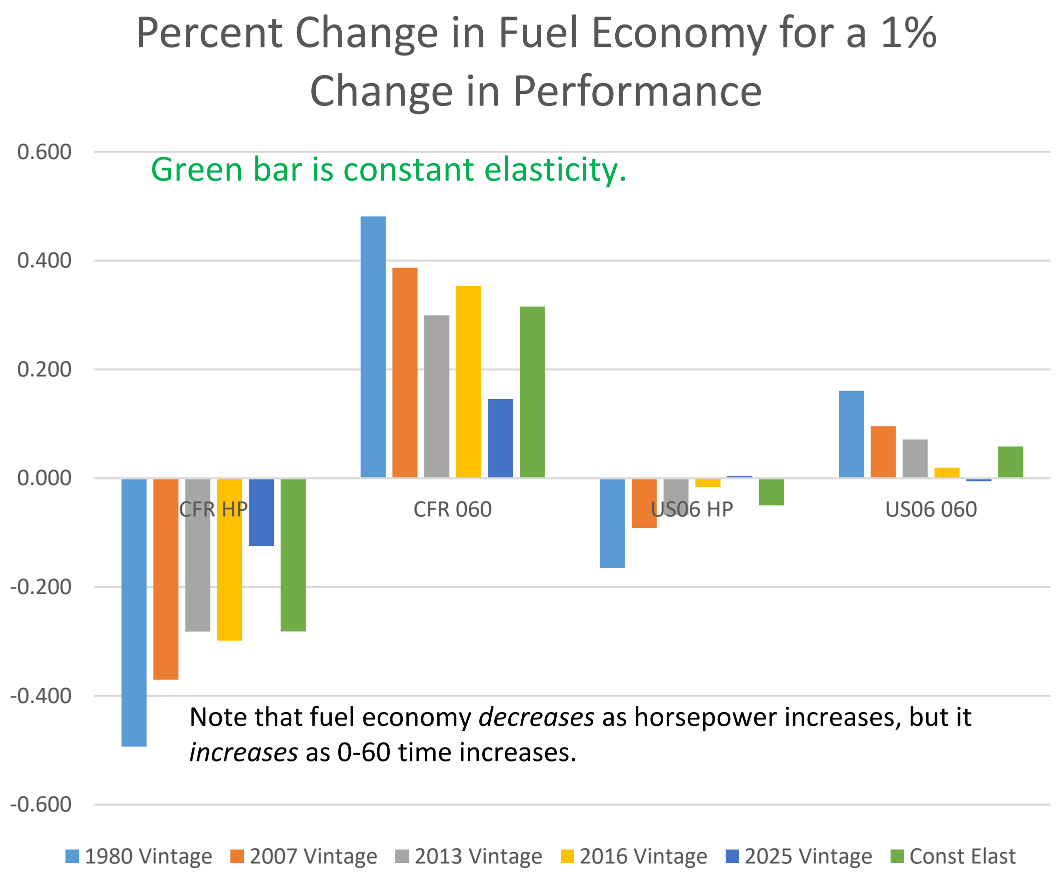
- MPG decreases as HP increases
- Significant shifts over time
- Varying the elasticities fits the data better

CFR vs. US06 MPG (Lines are regression, dots are raw data)



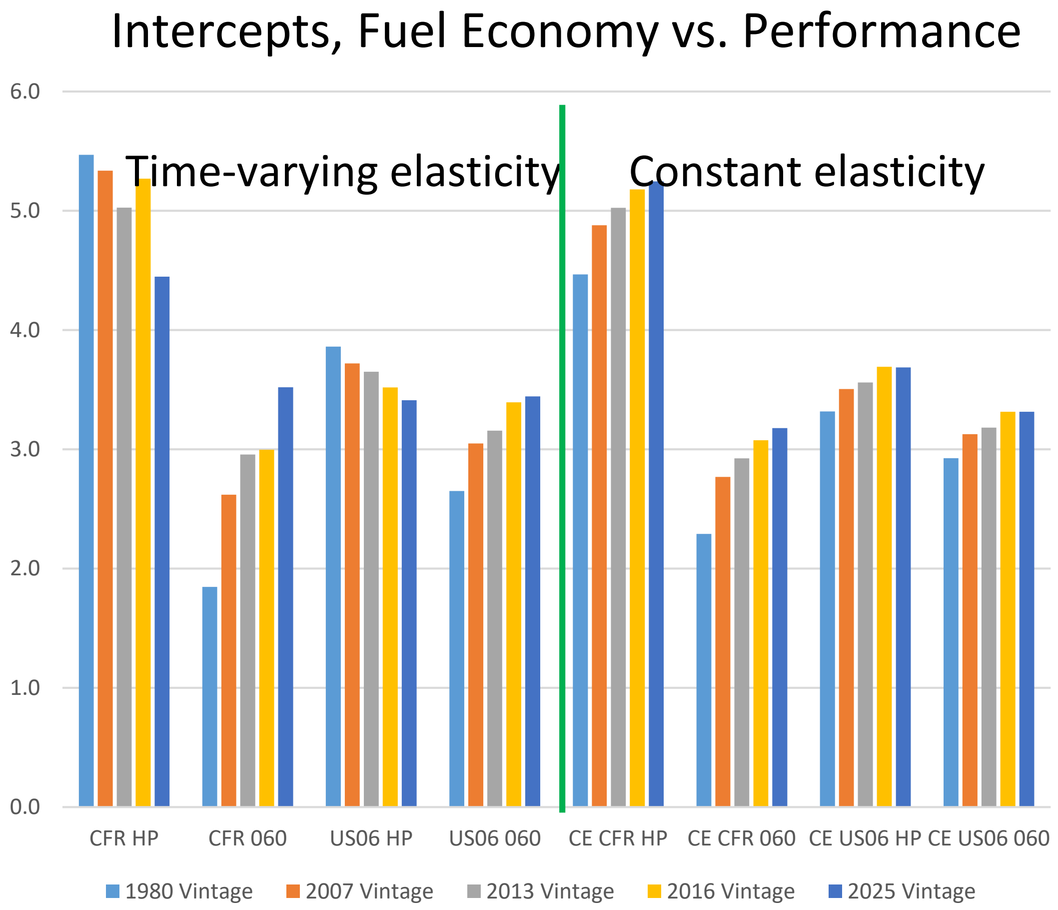
- CFR MPG is the regulatory measure; US06 MPG is aggressive driving
  - Real world is in between
- CFR produces higher mpg than US06
  - Axis is rescaled!
- US06 suggests less response of mpg to changes in performance
- For US06, almost no difference between 2016 and 2025

Does the Fuel Economy-Performance Elasticity Change over Time? -- Yes



- For all combinations of fuel economy & performance measures, the elasticity shrinks over time
- The elasticity is not sensitive to performance measures
  - Because of the bottom-up, ceteris paribus approach
- The elasticity is sensitive to how fuel economy is measured
  - The US06 measure is less sensitive

Are measures of innovation sensitive to metrics? -- Yes



- Using CFR MPG with HP appears to produce different magnitudes than other measures
  - The other measures are more similar to each other
- With time-varying elasticities,
  - Innovation decreases over time with HP
  - Innovation increases over time with 0-60 acceleration
  - This is consistent with getting faster 0-60 time from constant HP
- With constant elasticities, innovation always shows increases

How much fuel expenditure is incurred by a 1% improvement in performance?

Assumptions: 15 years; 12,000 miles/year; 4% discount rate; $2.50/gallon fuel cost

CFR MPG: used for certification

	HP	0-60
1980	$73	$71
2007	$41	$43
2013	$27	$29
2016	$25	$29
2025	$9	$11
Constant	$21 - $41	$23 - $47

US06 MPG: aggressive driving

	HP	0-60
1980	$25	$25
2007	$12	$13
2013	$8	$9
2016	$2	$2
2025	$0	-$1
Constant	$5 - $8	$6 - $9

- A 1% improvement in performance increases over time, but the cost of it is dropping.
- Values are similar for HP and for 0-60, but are much lower for US06 than for CFR MPG
  - Drivers experience less of an opportunity cost than CFR MPG implies

How much fuel expenditure is incurred by a 1-**unit** improvement in performance?

Assumptions: 15 years; 12,000 miles/year; 4% discount rate; $2.50/gallon fuel cost

CFR MPG: used for certification

	1 HP	1 sec 0-60
1980	$62	$456
2007	$22	$491
2013	$14	$356
2016	$12	$372
2025	$5	$139
Constant	$11-$36	$328-$471

US06 MPG: aggressive driving

	1 HP	1 sec 0-60
1980	$22	$163
2007	$6	$147
2013	$4	$111
2016	$1	$27
2025	$0	$8
Constant	$3-$7	$63-$101

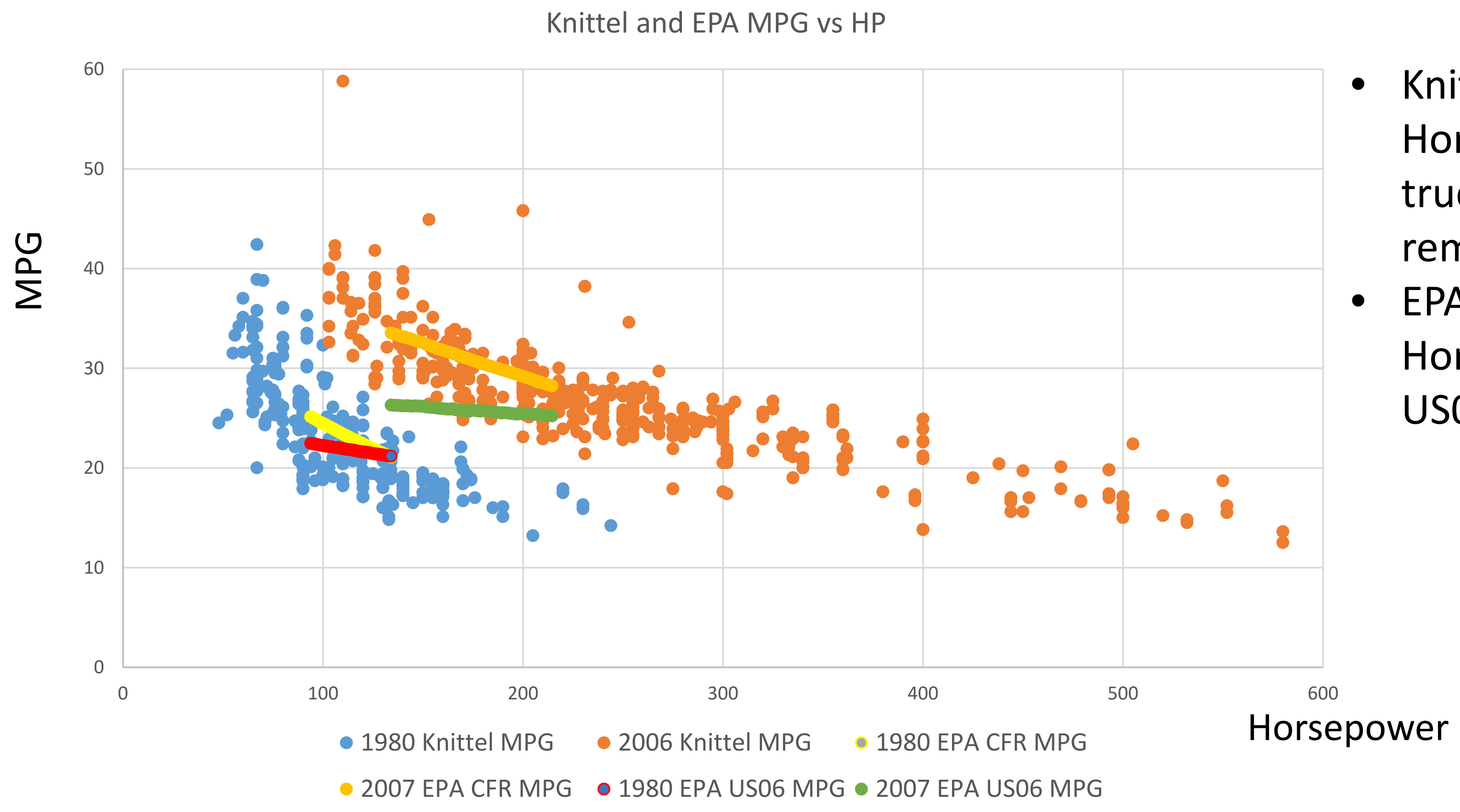
- A 1-second improvement in 0-60 time is much larger than a 1-HP improvement
- Drivers experience a lower opportunity cost for higher performance than CFR MPG implies
- Opportunity cost is dropping over time

Conclusions

- The top-down approach to estimating the tradeoff between power and fuel economy does not capture what happens for an individual powertrain
- The tradeoff between power & fuel economy has dropped over time
  - The cost of the tradeoff depends on the metrics being measured, and on the basis for comparison
  - Drivers' experienced tradeoffs are lower than those suggested by test-cycle MPG
- Measures of innovation are sensitive to metrics
- Economists may want to talk to engineers about this issue
  - And vice versa

Appendix

Comparison of Knittel & EPA HP vs MPG data



- Knittel data: 1980, 2006, Horsepower vs. MPG, with trucks and diesel vehicles removed
- EPA data: 1980, 2007, Horsepower vs. CFR MPG and US06 MPG