Product design & market responses to footprint-based fuel economy standards

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Research Priorities for the Midterm Review of CAFE & GHG Standards

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In the beginning...

Integrate engineering design & IO economic models:

Engineering vehicle design optimization

Standard differentiated-product oligopoly model

- Captures physics-based **tradeoffs between design variables** using engineering simulations
- Construct **engineering cost estimates** of design choices

- Captures **consumer choices** based on product designs and prices
- Captures **competitive behavior of firms** in a regulated market
- Econometrically estimate other vehicle costs

Consumers and competition are important to consider

Take-away points:

1. Vehicle designs, prices, consumer choices, and market share are all endogenous to CAFE/GHG regulated market

2. **Fuel economy/GHG outcomes depend on these responses**

3. Consumer demand and equilibrium models should not necessarily be used to determine standard stringency

4. **This type of research should be used to inform rule-making** to understand sensitivities, and avoid undesirable outcomes

Not the first to "endogenize" product design choices!

Our work builds on recent work by Klier and Linn (2010) and Knittel (2012) who econometrically estimate similar attribute trade-offs.

Why use simulated data in lieu of econometric approaches?

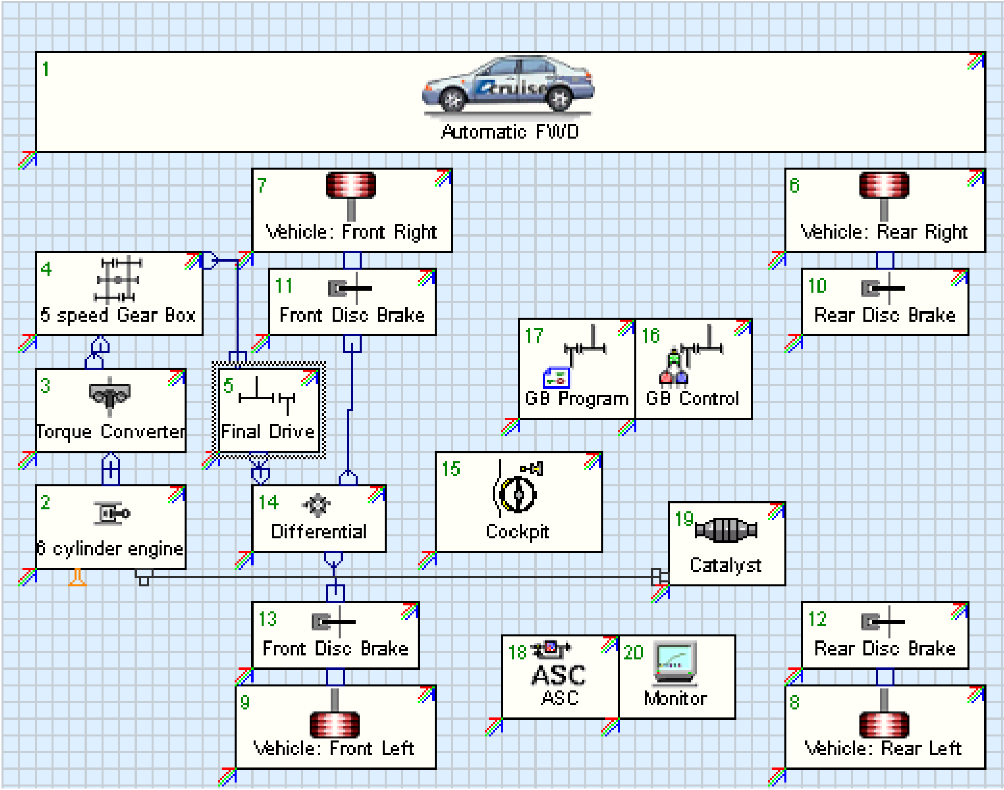
1. Many **feasible design parameter combinations are not observed in the data**, but may be optimal under alternative policy regimes.

2. **Correlations between observed attributes (e.g. acceleration) and unobservable attributes** that affect fuel economy (such as engine lubricants) can make it difficult to identify design trade-offs econometrically.

Engineering simulations capture vehicle design trade-offs

- "AVL Cruise" is a commercial model used by the automotive industry to inform powertrain design
- We combine simulations, NHTSA's technology data, and engineering cost estimates to estimate tradeoffs

AVL Cruise 3.1



Nest this design model within a familiar oligopoly framework

$$\max_{acc_j, tech_j, ftp_j, p_j \ \forall j \in \mathfrak{J}_f} \pi_f = \sum_{j \in \mathfrak{J}_f} q_j \left(p_j - c_j\right)$$

Maximize profit with respect to vehicle footprint, acceleration, level of technology, and price of each vehicles firm f produces, $j \in \mathfrak{J}_f$

s.t.

$$\boldsymbol{g} \leq \boldsymbol{0}$$

Subject to CAFE standards

$$ftp_j - 1.1 ftp_j^0 \leq 0$$

Increases in footprint restricted to 10% or less

where

$$wt_j = h(ftp_j)$$

Curbweight increases with vehicle footprint

$$eff_j = f(acc_j, tech_j, wt)$$

Fuel efficiency calculated from curbweight, acceleration performance, and technology features, based on engineering simulations

$$c_j = w(acc_j, tech_j, ftp_j) + \omega_j$$

Costs dependent on vehicle footprint, acceleration performance, and technology features

$$q_j = g(\{p_k, acc_k, eff_k, ftp_k\}: k \in \mathfrak{J}_f \forall f)$$

Demand, dependent on all vehicles' footprints, prices, and acceleration

Assume production costs increase at a ratio of 1:1

Assume **fixed costs do not vary with footprint** decisions because all design changes occur during scheduled product redesigns and subsystems are (re)designed after target dimensions are set

Assume production costs **increase 1% with a 1% increase in footprint**

We perform sensitivity tests on these assumptions

Ranges of demand parameters used from literature

Estimating demand parameters requires addressing correlation of unobserved attributes with vehicle footprint, fuel economy, acceleration performance, and price

Instead of solving endogeneity problem, **examine potential for incentive over range of plausible demand parameters** from the literature

(e.g., Goldberg '98, Greene & Liu '87 Jacobsen '10, Helfand & Wolverton '11, Klier & Linn '08)

	Range of mean elasticity	Coefficient range
Price	2.0–3.1	0.7–1.0
	Range of estimated willingness to pay	Coefficient range with price coefficient=1.0
Footprint (sq. ft)	\$340–\$2,000	2.12–12.71
Acceleration performance (0.01 hp/lb)	\$160–\$5,500	0.06–2.07
Fuel efficiency (gal/100 mi)	\$800–\$9000	0.07–0.80

We Make Many Simplifying Assumptions

Many possible technology options are not included

Demand model (simple logit) does not capture different preferences across the population

Use a static equilibrium model to examine possible design changes between 2006-2014

We include all vehicle model and engine options (~470 vehicles total) but not more-detailed vehicle package options

Incentive may be considerable depending on preferences

Sales-weighted average footprint increases in all cases **except when footprint preference is low and acceleration preference is high**

In all other cases, **average fuel economy is 1.4–3.9 mpg lower** than if vehicle sales and size remain unaffected, **undermining fuel economy gains by 20-53%**

2014 CAFE Analysis

Preference for fuel efficiency / Preference for acceleration	Preference for footprint: Low	Mid	High
High	-1.4 sq. ft.	+3.8 sq. ft.	+7.0 sq. ft.
Mid	+1.5 sq. ft.	+7.5 sq. ft.	+9.2 sq. ft.
Low	+2.1 sq. ft.	+9.6 sq. ft.	+13.4 sq. ft.

Incentive exists over large range of consumer preferences

Price Sensitivity	Preference for fuel efficiency	Preference for acceleration	Preference for vehicle size	Sales-weighted average change in size
High	Mid	High	Mid	+4.0 sq ft
High	Mid	Low	Mid	+9.4 sq ft
High	High	Mid	Mid	+5.9 sq ft
High	Low	Mid	Mid	+9.2 sq ft
Mid	Mid	Mid	Mid	+10.5 sq ft
Low	Mid	Mid	Mid	+11.3 sq ft
High	Low	High	Mid	+5.9 sq ft
High	High	Low	Mid	+9.3 sq ft
High	Mid	High	Low	-1.0 sq ft
High	High	Mid	Low	+1.3 sq ft
Mid	Mid	Mid	Low	+4.2 sq ft
Low	Low	Low	High	+16.1 sq ft

Consumers and competition are important to consider

Summarizing Thoughts:

- We demonstrate that **fleet mix and footprint decisions depend on regulations & consumer preferences** and that fuel economy/GHG outcomes depend (potentially substantially) on these responses

  - ➢ Real world: MY2013 light truck and passenger car average footprints trending to be larger than projected

- Flattening the standard (or creating consumer incentives for fuel efficiency) will improve the chance of reaching CAFE/GHG goals

- **Designing the standards such that no incentive exists is extremely difficult** considering:

  - **Average footprint depends on many factors**, including engineering tradeoffs between vehicle attributes, consumer preferences, production costs, and market structure

  - these factors **may vary across vehicle models** and are **likely to change over time**

Need to understand, track and respond to footprint changes

Future research, data, and regulatory suggestions

- Consider demand & oligopolistic behavior affecting fleet mix in rulemaking to guard against undesirable outcomes
- Track and report regularly on sales-weighted average footprint for manufacturers and entire fleet
- Build in the flexibility to make necessary adjustments to the standards to correct undesirable trends in the market's response
- Learn more about the sensitivity of CAFE/GHG outcomes to consumer preferences, regulation design, and technology options
  - In particular: dynamics of product design schedules & banking/borrowing credits, and changes in consumer preferences over time
- Facilitate easy sharing of data & research between agencies and researchers: detailed vehicle attributes, sales projections, models, etc.