About me

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A brief overview

• Introduction to CAFE standards
• Mathematical formulation of rulemaking
• Emissions implications of current standard
• Effects of other policies sponsoring AFVs
• Emissions implications of policy interactions
Historical CAFE Standards and Expected Joint Rulemaking Standard Requirements Through 2025

1: Standards set for passenger vehicles (1978)
2: Standards set for light-duty trucks (1979)
3: DoT decreases car standards (1986)
4: DoT sets car standards to 27.5 MPG (1990)
5: Congress sets truck standards to 20.7 MPG (1997)
6: Bush Administration sets new truck standards (2005)
7: CAFE changed to footprint based (2008)
Requirements changed to a footprint based standard

Footprint based standards for passenger cars (left) and light-duty trucks (right) from 2012 through 2025.
Most manufacturers met standard requirements in 2009

Compliance of vehicles in 2009 with future standards reference curves
## Studies of CAFE

<table>
<thead>
<tr>
<th>Impacts on energy, economy, and environment</th>
<th>Older studies of CAFE effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greene (1998), Gerard &amp; Lave (2003),</td>
<td></td>
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<tr>
<td>Kleit (2004)</td>
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<tr>
<td>EPA (2010)</td>
<td>Estimates current implementation of</td>
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<tr>
<td></td>
<td>standard will reduce 1 billion</td>
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<tr>
<td></td>
<td>metric tons of CO₂</td>
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<tr>
<td>Karplus &amp; Paltsev (2012), Morrow et al.</td>
<td>Alternative methods to estimate</td>
</tr>
<tr>
<td>(2010), Cheah et al. (2010)</td>
<td>emissions reductions from CAFE</td>
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<td></td>
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<tr>
<td>Influences on automotive design</td>
<td></td>
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<tr>
<td>Shiau et al. (2009), Whitefoot et al.</td>
<td>Strategies of compliance through</td>
</tr>
<tr>
<td>(2011), Whitefoot &amp; Skerlos (2012)</td>
<td>design decisions</td>
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<tr>
<td></td>
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<tr>
<td>Unintended policy effects</td>
<td></td>
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<tr>
<td>Sallee (2008)</td>
<td>Taking advantage of FFV credits to</td>
</tr>
<tr>
<td></td>
<td>estimate compliance costs</td>
</tr>
<tr>
<td>Boulder, Jacobsen, Benthem (2012)</td>
<td>Leakage effects means no gains from</td>
</tr>
<tr>
<td></td>
<td>EV sales</td>
</tr>
</tbody>
</table>
Complex policies can lead to unintended consequences

“With CAFE standards in place...putting more electric (or other high-fuel-economy vehicles) on the road will produce little or no net reduction in total gasoline consumption and greenhouse gas emissions” – Congressional Budget Office Report

• We in fact will demonstrate that the adoption of alternative fuel vehicles is results in a net increase of greenhouse gas emissions
Formulating compliance with GHG standards mathematically

\[
\sum_{j} \frac{n_j s_j}{N} = \sum_{j} \frac{n_j r_j}{N}
\]

- \( j \) – Vehicle model index
- \( N \) – Total vehicles sold
- \( n \) – Number of vehicles of model \( j \) sold
- \( s \) – Emissions standard for model \( j \)
- \( r \) – Emissions rate for model \( j \)
\[
\frac{\sum j \ n_j \ s_j}{N} = \frac{\sum j \ n_j \ r_j}{N}
\]

Consider:

- Two Camrys and two Priuses are sold
- On the left-hand side: \([200*2 + 150*2]/4 = 175\]
- On the right-hand side: \([250*2 + 100*2]/4 = 175\]
- Balanced! Individual vehicles do not need to have \(r = s\), but at the manufacturer level everything must be balanced.

\[
\begin{align*}
\text{Toyota Camry} & \quad r = 250 \text{ g/mi} \\
\text{Toyota Prius} & \quad r = 100 \text{ g/mi} \\
\text{} & \quad s = 200 \text{ g/mi} \\
\text{} & \quad s = 150 \text{ g/mi}
\end{align*}
\]
There are complex incentives for AFVs in the rulemaking

- Weights: multiplicatively affect emissions rate for alternative fuel vehicles
- Multipliers: Increase the accounting of sales for alternative fuel vehicles

### AFV Incentives in 2012-2016

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Proportion Operating on Alternative Fuel</th>
<th>Multiplier</th>
<th>Weighting Factor</th>
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</thead>
<tbody>
<tr>
<td>ICV</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>FFV</td>
<td>0.5</td>
<td>1</td>
<td>0.15</td>
</tr>
<tr>
<td>CNG</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BEV</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PHEV</td>
<td>0.29-0.66</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>FCV</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

### AFV Incentives in 2017-2025

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>ICV</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>FFV</td>
<td>0.15</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CNG</td>
<td>1</td>
<td>1.6</td>
<td>1.45</td>
<td>1.3</td>
<td>1</td>
<td>1</td>
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<tr>
<td>BEV</td>
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<td>2.0</td>
<td>1.75</td>
<td>1.5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PHEV</td>
<td>0.29-0.66</td>
<td>1.6</td>
<td>1.45</td>
<td>1.3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>FCV</td>
<td>1</td>
<td>2.0</td>
<td>1.75</td>
<td>1.5</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Balancing to CAFE

\[ \frac{\sum_{j} n_{j}s_{j}}{N} = \frac{\sum_{j \in C} n_{j}r_{j} + \sum_{j \in A} \left( w_{j}p_{j}r_{j}^{A} + (1 - p_{j})r_{j}^{G} \right) n_{j}}{\sum_{j \in C} n_{j} + \sum_{j \in A} n_{j}m_{j}} \]

- \( C \) – conventional ICVs
- \( A \) – alternative fuel vehicles
- \( w \) – weights
- \( p \) – proportion of time spent on alternative fuel
- \( m \) – multipliers
To incentivize or not to incentivize...

Balancing CAFE without AFV incentives:

\[
\frac{n_1 s_1 + n_2 s_2 + \sum_{j=3}^{J} n_j s_j}{N} = \frac{n_1 \left(p_1 r_1^A + (1 - p_1) r_1^G\right) + n_2 r_2 + \sum_{j=3}^{J} n_j r_j}{N}
\]

Rest of vehicles balanced to standard

Balancing CAFE with AFV incentives:

\[
\frac{n_1 s_1 + n_2 s_2 + \sum_{j=3}^{J} n_j s_j}{N} = \frac{n_1 \left(w_1 p_1 r_1^A + (1 - p_1) r_1^G\right) + n_2 r_2' + \sum_{j=3}^{J} n_j r_j}{N + n_1 (m_1 - 1)}
\]

Increased emission rate:

\[
\Delta r_2 = r_2' - r_2 = \frac{sn_1 (m_1 - 1) + n_1 (1 - w_1) p_1 r_1^A}{n_2}
\]
Calculating emissions increase per vehicle due to incentives: Chevy Volt example

Relative emission rates for a Chevy Volt and a balancing vehicle, with and without AVIs

Multipliers come into effect in 2016
Emissions increase per vehicle due to incentives: variety of AFVs

Incremental emission rate increase from balancing vehicle against a range of AFV models
Estimating cumulative increase in emissions due to CAFE AVIs

Projections of AFV sales through 2025 by EIA

Increase in annual emissions due to AVIs based on EIA forecasts
Discussion

• On a per car basis, the incentives add a car of emissions on the road for every AFV sold
• Cumulative effect of the AVIs is about 30-50 million tons of CO$_2$
• Policy push for AFV adoption may pay off in the long-run, but there are clear short-term costs in emissions
A tale of two policies: how fuel economy standards and promotion of alternative vehicle sales can increase emissions
Interacting policies can worsen the emissions consequences

• If a consumer would have purchased an ICV but instead purchases an AFV due to an exogenous policy factor:
  – AFV incentive effect occurs
  – Additional emissions from difference in vehicle production (battery manufacturing emissions for EVs)
  – Compounds AFV incentive interaction by increasing magnitude of AFV sales
We consider four combinations of policies

<table>
<thead>
<tr>
<th>Scenario</th>
<th>CAFE standards</th>
<th>CAFE AFV incentives</th>
<th>ZEV mandate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure CAFE (a)</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>CAFE + ZEV (b)</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>CAFE + AFVI (c)</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>CAFE + ZEV + AFVI (d)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Total emissions differences are small due to relatively small sales of AFVs
Cumulative New Vehicle Lifetime CO2 Emissions (billions of tons)

<table>
<thead>
<tr>
<th>Technology</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV</td>
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<tr>
<td>ICV</td>
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<td>PHEV10</td>
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<td>PHEV40</td>
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<tr>
<td>Balancing Vehicle</td>
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</tr>
</tbody>
</table>

Policy Scenario

Technology:
- BEV
- CNG
- FCV
- FFV
- ICV
- PHEV10
- PHEV40

Balancing Vehicle
Relative emissions differences can be quite large

Policy Scenarios

Difference in Cumulative CO2 Emissions (millions of tons)

<table>
<thead>
<tr>
<th></th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions (millions of tons)</td>
<td>0</td>
<td>60</td>
<td>140</td>
</tr>
</tbody>
</table>
If other states adopt ZEV, emissions impact can be quite large.
Is the push for AFVs worth it?

• AFV incentives and ZEV standards can lead to emissions increases of over 100 million tons of CO$_2$, over 10% decrease in emissions savings of CAFE.

• Quantification of short-term costs are necessary to evaluate effectiveness of policies.

• Can inefficiencies be avoided?
Future Work

• In the first half:
  – Generalized formulation for both changes in numbers sold and emissions rates
  – 2-cycle versus 5-cycle

• In the second half:
  – Better estimates using state level sales data for baseline effects of ZEV
Acknowledgments

• Diana Ginnebaugh for inviting me and organizing the talk as well as the Precourt Energy Efficiency Center and Sustainable Transportation Seminar Series for hosting me.

• I would like to thank the Center for Climate and Energy Decision Making which has supported my graduate studies through National Science Foundation (SES-0949710), as well as the Bertucci Fellowship for funding.

• My advisers Professor Ines Azevedo and Professor Jeremy Michalek as well as their respective research groups the Climate and Energy Decision Making Center and the Vehicle Electrification Group.

• William Chernicoff, Tom Stricker, Rick Gazelle, and Robert Wimmer; members of the Energy and Environment Group at Toyota Motors North America for providing industry insight into CAFE/GHG standards.

• Tom Cackette, Anna Wong, and Analisa Bevan; members of the California Air Resources Board for providing insight on the workings of the Zero Emissions Vehicle mandate in California.