International spillovers from fuel economy policies

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Introduction

• Increases in fuel economy (CAFE) standards and technological innovation go hand in hand
  – Bento, Roth and Wang (2015)

• Fuel prices also matter for induced technical change
  – Crabb and Johnson (2010)

• Policy studies focus on single market

• International knowledge spillovers from domestic induced innovation
  – Verdolini and Galeotti (2011)
Directed technical change in the auto industry

- Aghion et al. (2016) study “dirty” (internal combustion engine) and “clean” (e.g., electric, hybrid, and hydrogen) patents across 80 countries.

- Firms tend to innovate more in clean (and less in dirty) technologies when facing higher tax-inclusive fuel prices.

- Path dependence in the type of innovation (clean/dirty) both from aggregate spillovers and from the firm’s own innovation history.

- Ignore other fuel economy policies.
Important characteristics of auto manufacturing

- Large fixed costs, capital and technology intensive
- Highly concentrated industry within markets
  - Largest 4 firms account for 60% of the U.S. market
- Each firm manages a full product line
- Significant brand loyalty
  - Train and Winston (2007)
- Global production and sales

<table>
<thead>
<tr>
<th>Firm</th>
<th>Market share (%; 2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM</td>
<td>17</td>
</tr>
<tr>
<td>Ford</td>
<td>15</td>
</tr>
<tr>
<td>Toyota</td>
<td>14</td>
</tr>
<tr>
<td>Fiat/Chrysler</td>
<td>13</td>
</tr>
<tr>
<td>Honda</td>
<td>9</td>
</tr>
<tr>
<td>Nissan</td>
<td>9</td>
</tr>
<tr>
<td>All other</td>
<td>23</td>
</tr>
</tbody>
</table>
Shared platforms, engines, and technologies

• “common design, engineering, and production efforts, as well as major components over a number of outwardly distinct models and even types of cars”

Examples of cars sharing the Fiat Mini platform

Ford Ka  Fiat Panda  Fiat 500  Fiat Uno  Lancia Ypsilon
Volkswagen
WORLDWIDE DELIVERIES OF THE GROUP’S MOST SUCCESSFUL MODEL RANGES IN 2016
Vehicles in thousands

- Golf: 990
- Jetta: 940
- Polo: 781
- Passat: 684
- Lavida: 550
- Tiguan: 524
- ŠKODA Octavia: 436
- Audi A3: 370

* Shared platforms
Spillover mechanisms

- Firm-owned patents
- Shared costs
  - Centralized design
  - Common platforms
  - Limited number of plants
  - Shared engines
  - Fixed costs of tailoring
Model of a representative firm

• Let this firm produce two types of vehicles (Small and Large) in each of two markets (East and West)
• Brands (makes) and models are fixed within our timeframe
• Manufacturer can invest in technology, modify fuel economy, and set prices (Bertrand competition).
Manufacturing costs

• Manufacturer chooses a retail price $P_{ij}$ and a fuel consumption rate $\varphi_{ij}$ for vehicle of type $i$ in region $j$
• Manufacturer-specific technology $k$ and model-specific technology $h_i$.
• Production costs $C_{ij}(\varphi_{ij}, k, h_i)$
  – decreasing and convex
  – technologies lower the marginal cost of improving fuel economy
Consumer demand

• Demand for class $i$ in region $j$ is a function of the vector of total vehicle costs—the purchase price plus discounted fuel consumption costs—for all vehicles in country $j$ ($q_{ij}(P_j + \phi_j F_j)$).

• Demand in class $i$ is decreasing in its own price and fuel consumption rate, and weakly increasing in those of other classes.
Profits for the representative manufacturer

- Retail price less production costs, multiplied by the output of each model class

\[ V(P_j, \phi_j, k, h) = \sum_j \left( \sum_i (P_{ij} - C_{ij}(\phi_{ij}, k, h_i))q_{ij}(P_j + \phi_j F_j) - A(h) \right) - B(k) \]

- Profit-maximizing price

\[ \frac{\partial V(P, \phi)}{\partial P_{ij}} = q_{ij} + \sum_s \pi_s \frac{\partial q_{sj}}{\partial P_i} = 0, \text{ where } \pi_s = P_s - C_s(.) \]

\[ \rightarrow P_{ij} = C_{ij}(.) \frac{\eta_{iij}}{\eta_{iij} + 1} + \sum_{s \neq i} \pi_s \frac{-\eta_{siij}}{(\eta_{iij} + 1)} q_{ij}, \text{ where } \eta_{siij} = \frac{\partial q_{sj}}{\partial P_{ij}} \frac{P_{ij}}{q_{sj}} \]
Choice of fuel consumption rate

- Reduce fuel consumption rate until the change in the unit cost just equals the fuel price in region \( j \)

\[
\frac{\partial V}{\partial \phi_{ij}} = - \frac{\partial C_{ij}(.)}{\partial \phi_{ij}} q_{ij} + F_j \sum_{s_j} \pi_{s_j} \frac{\partial q_{s_j}}{\partial P_{ij}} = 0
\]

\[
\rightarrow - \frac{\partial C_{ij}(.)}{\partial \phi_{ij}} = F_j
\]
Technology investment

- Occurs until marginal reduction in global production costs equals marginal investment costs

- Model-specific technology

\[
\frac{\partial V}{\partial h_i} = - \sum_j \frac{\partial C_{ij}(.)}{\partial h_i} q_{ij} - A_i'(h_i) = 0
\]

- Make-wide technology

\[
\frac{\partial V}{\partial k} = - \sum_i \sum_j \frac{\partial C_{ij}(.)}{\partial k} q_{ij} - B'(m) = 0
\]
Effect of increasing fuel taxes in region $E$

- Let $C_{ij}(.) = C_{ij}^0 e^{-a_i^i \phi - a_h^i h - a_k^i k}$.
- Fuel economy rises in that market in response to price and technology changes

$$\frac{d \phi_{iE}^i}{dF_E} = \frac{1}{a_i^i} \left( 1 / (a_i^i C_{ij}) + a_h^i \frac{dh_i}{dF_E} + a_k^i \frac{dk}{dF_E} \right)$$

- Fuel economy in the other market will rise to the extent that technology improves

$$\frac{d \phi_{iW}^i}{dF_E} = \frac{1}{a_i^i} \left( a_h^i \frac{dh_i}{dF_E} + a_k^i \frac{dk}{dF_E} \right)$$
Firm incentives with fuel economy standards

- CAFE standards add constraint: $\sum_i \phi_{ij} q_{ij} \leq \sum_i \bar{\phi}_{ij} q_{ij}$ to profit-maximization problem:
  
  $$L = V(P_j, \phi_j, k, h) - \lambda \sum_i (\phi_{ij} - \bar{\phi}_{ij}) q_{ij} (P_j + \phi_j F_j)$$

- Price setting involves implicit tax / subsidy
  
  $$P_{ij} = \left(C_{ij}(.) + \lambda (\phi_{ij} - \bar{\phi}_{ij}) \right) \frac{\eta_{ij}}{(\eta_{ij} + 1)} + \sum_{s \neq i} \tilde{\pi}_{ij} \frac{-\eta_{sij}}{(\eta_{ij} + 1)} q_{sij},$$

  where $\tilde{\pi}_{ij} = P_{ij} - C_{ij}(.) - \lambda_j (\phi_{ij} - \bar{\phi}_{ij})$

- Fuel consumption rate involves shadow value
  
  $$-\frac{\partial C_{ij}(.)}{\partial \phi_{ij}} = F_j + \lambda_j$$
Effect of increasing fuel taxes in $E$ when CAFE standards bind in $W$

- Fuel economy improvements loosen the CAFE constraint:
  
  $$ - \frac{d \phi_{iw}}{d F_E} = \frac{1}{a^i_h} \left( \frac{1}{a^i_\phi C_{ij}} \frac{d \lambda_w}{d F_E} + a^i_h \frac{dh_i}{d F_E} + a^i_k \frac{dk}{d F_E} \right) $$

- The impact on the West then is not, on average, any fuel economy improvement, but rather a decrease in the cost of meeting the standard, and thus lower vehicle costs and greater sales (and then, correspondingly, more emissions...).
Comparing technology investment incentives from a fuel tax increase in $E$

- Change in model / brand technology depends on model demand for fuel economy, changes in vehicle sales, and change in the CAFE constraint

$$\frac{dh_i}{dF_E} = \sum_j \frac{a_i^j C_{ij}}{A_i''(h_i)} \left( \frac{dq_{ij}}{dF_E} - \left( a_i^j \frac{d\Phi_{ij}}{dF_E} + a_i^h \frac{dh_i}{dF_E} + a_i^k \frac{dk}{dF_E} \right) q_{ij} \right)$$

$$= \frac{a_i^j}{A_i''(h_i)} q_{iE} + \frac{a_i^j C_{iE}}{A_i''(h_i)} \left( \frac{dq_{iE}}{dF_E} \right) + \frac{a_i^j C_{iW}}{A_i''(h_i)} \left( \frac{dq_{iW}}{dF_E} \right) + \frac{q_{iW}}{a_i^j C_{iW}} \left( \frac{d\lambda_W}{dF_E} \right)$$

- Less international spillover benefit when other region regulates average fuel economy
Raising CAFE standards

- In regulating region, effects on FE decisions similar via increase in $\lambda$ instead of $F$.
- Effects on vehicle sales (and technology) different
  - all else equal, same production cost and retail price increase, but the fuel cost component of demand will fall, not rise, in the regulating region
  - vehicle demand is higher with CAFE, strengthening the incentive to invest in technologies, further lowering vehicle costs.
- Expect larger spillover effects from an increase in CAFE standards than from a fuel tax increase
  - greater reliance on technological improvements.
- Spillover benefits are still lower when the other region regulates with a standard instead of a fuel tax…
## Summary

<table>
<thead>
<tr>
<th>Policy change in E</th>
<th>No CAFE in W</th>
<th>CAFE in W</th>
</tr>
</thead>
</table>
| **Fuel tax / price increase** | • Fuel economy increases in both regions.  
  • Sales fall in *E* (particularly for large cars) and increase in *W*.  
  • Technologies improve. | • Fuel economy does not change in *W*.  
  • Sales fall in *E* and increase in *W*.  
  • Less incentive for technology improvement. |
| **Increase in standard** | • Fuel economy increases in both regions.  
  • Sales higher in *E* (than with fuel tax) and increase in *W*.  
  • More incentive for technology improvement. | • Fuel economy does not change in *W*.  
  • Sales higher in *E* (than with fuel tax) and increase in *W*. |
Predictions

• Innovation by manufacturers with larger share of sales in regions with [binding] FE regulations should be less responsive to fuel price / tax changes
  – Different than “path dependence”

• Changes in FE standards should have larger innovation spillovers than fuel price changes
  – Still have differential effect depending on regulatory patterns
  – Confounding problem of endogenous regulation
  – Crabb and Johnson find no effect of standards on innovation
Other policies:
• Taxes on vehicle weight and engine displacement (Japan)
• Feebates (France)
• Hybrid / EV incentives…
Thanks!

• This is ongoing research – please contact us before citing (fischer@rff.org)
• Feedback welcome!