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

Firm	*Market share (%; 2016)*
GM	17
Ford	15
Toyota	14
Fiat/Chrysler	13
Honda	9
Nissan	9
All other	23

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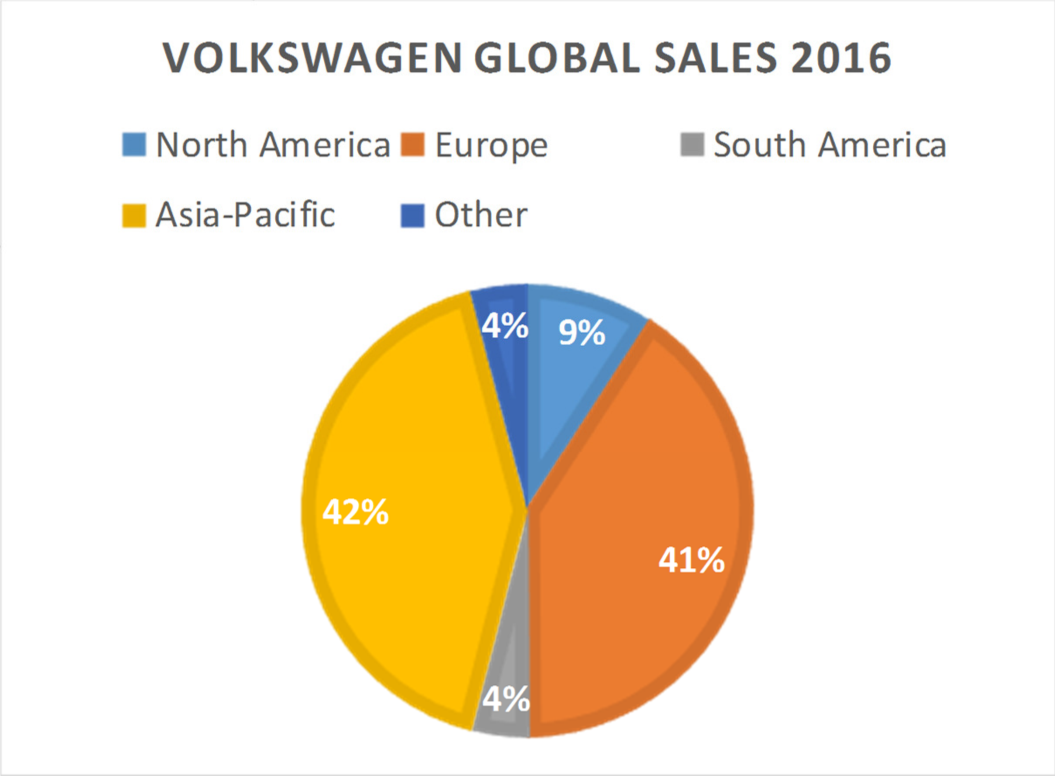
GM GLOBAL SALES 2016
North America
Europe
South America
China
GM International
7%
36%
39%
12%
6%


VOLKSWAGEN GLOBAL SALES 2016
North America
Europe
South America
Asia-Pacific
Other
4%
9%
42%
41%
4%

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

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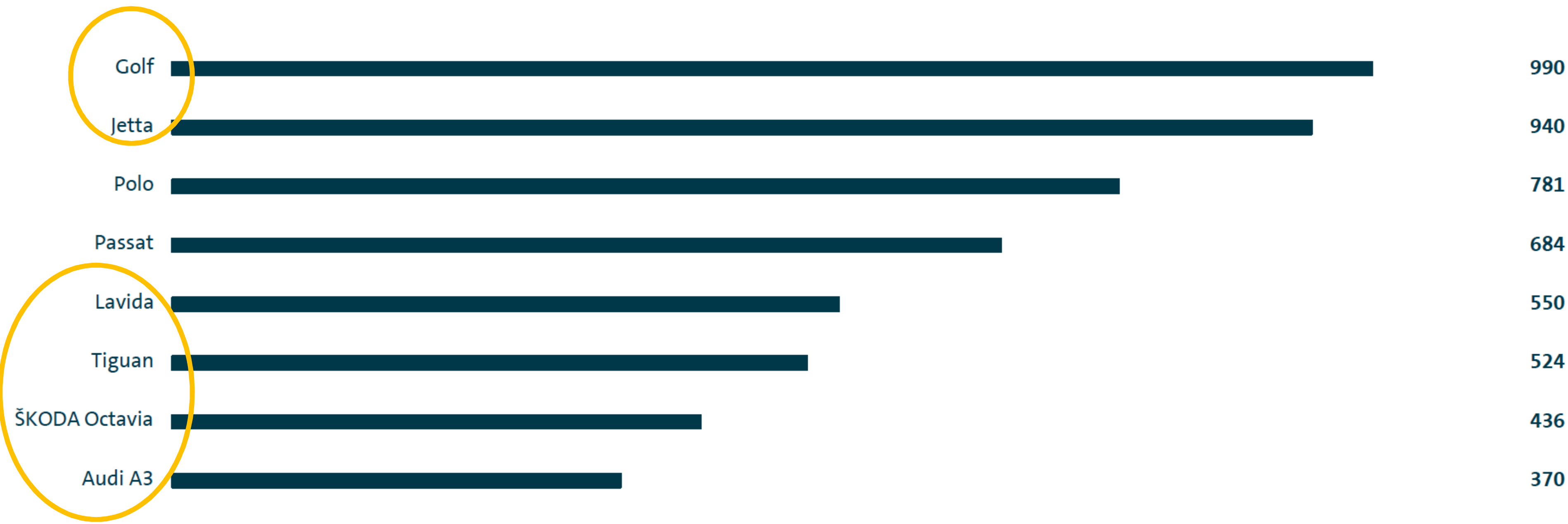
Volkswagen

WORLDWIDE DELIVERIES OF THE GROUP'S MOST SUCCESSFUL MODEL RANGES IN 2016

Vehicles in thousands



* Shared platforms

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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 φ_{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

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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* ($q_{ij}(\mathbf{P}_j + \boldsymbol{\varphi}_j \mathbf{F}_j)$).
- Demand in class *i* is decreasing in its own price and fuel consumption rate, and weakly increasing in those of other classes

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Profits for the representative manufacturer

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

$$V(\mathbf{P}_j, \boldsymbol{\varphi}_j, k, \mathbf{h}) = \sum_j \left(\sum_i (P_{ij} - C_{ij}(\phi_{ij}, k, h_i)) q_{ij}(\mathbf{P}_j + \boldsymbol{\varphi}_j \mathbf{F}_j) - A(h) \right) - B(k)$$

- Profit-maximizing price

$$\frac{\partial V(\mathbf{P}, \boldsymbol{\varphi})}{\partial P_{ij}} = q_{ij} + \sum_s \pi_{sj} \frac{\partial q_{sj}}{\partial P_i} = 0, \text{ where } \pi_{sj} = P_{sj} - C_{sj}(.)$$

$$\rightarrow P_{ij} = C_{ij}(.) \underbrace{\frac{\eta_{iij}}{\eta_{iij} + 1}}_{>1 \text{ (markup)}} + \sum_{s \neq i} \pi_{sj} \frac{-\eta_{sij}}{(\eta_{iij} + 1)} \frac{q_{sj}}{q_{ij}}, \text{ where } \eta_{sij} = \frac{\partial q_{sj}}{\partial P_{ij}} \frac{P_{ij}}{q_{sj}}$$

Choice of fuel consumption rate

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

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

$$\rightarrow -\frac{\partial C_{ij}(.)}{\partial \phi_{ij}} = F_j$$

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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

$$\frac{\partial V}{\partial k} = -\sum_i \sum_j \frac{\partial C_{ij}(.)}{\partial k} q_{ij} - B'(m) = 0$$

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Effect of increasing fuel taxes in region E

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

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

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

$$-\frac{d\phi_{iW}}{dF_E} = \frac{1}{a_\phi^i}\left(a_h^i \frac{dh_i}{dF_E} + a_k^i \frac{dk}{dF_E}\right)$$

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Firm incentives with fuel economy standards

- CAFE standards add constraint: $\Sigma_i \phi_{ij} q_{ij} \leq \Sigma_i \bar{\phi}_{ij} q_{ij}$ to profit-maximization problem:

$$L = V(\mathbf{P}_j, \boldsymbol{\varphi}_j, k, \mathbf{h}) - \lambda_j \sum_i (\phi_{ij} - \bar{\phi}_{ij}) q_{ij} (\mathbf{P}_j + \boldsymbol{\varphi}_j \mathbf{F}_j)$$

- Price setting involves implicit tax / subsidy

$$P_{ij} = \left(C_{ij}(.) + \lambda(\phi_{ij} - \bar{\phi}_{ij})\right) \frac{\eta_{iij}}{\left(\eta_{iij} + 1\right)} + \sum_{s \neq i} \tilde{\pi}_{ij} \frac{-\eta_{sij}}{\left(\eta_{iij} + 1\right)} \frac{q_{sj}}{q_{ij}},$$

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

- Fuel consumption rate involves shadow value

$$-\frac{\partial C_{ij}(.)}{\partial \phi_{ij}} = F_j + \lambda_j$$

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Effect of increasing fuel taxes in *E* when CAFE standards bind in *W*

- Fuel economy improvements loosen the CAFE constraint:

$$-\frac{d\phi_{iW}}{dF_E} = \frac{1}{a_\phi^i}\left(1/\left(a_\phi^i C_{ij}\right)\frac{d\lambda_W}{dF_E} + a_h^i \frac{dh_i}{dF_E} + a_k^i \frac{dk}{dF_E}\right)$$

- 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...).

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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

$$\frac{dh_i}{dF_E} = \sum_j \frac{a_h^i C_{ij}}{A_i''(h_i)} \left(\frac{dq_{ij}}{dF_E} - \left(a_\phi^i \frac{d\phi_{ij}}{dF_E} + a_h^i \frac{dh_i}{dF_E} + a_k^i \frac{dk}{dF_E} \right) q_{ij} \right)$$

$$= \frac{a_h^i / a_\phi^i}{A_i''(h_i)} q_{iE} + \frac{a_h^i C_{iE}}{A_i''(h_i)} \left(\frac{dq_{iE}}{dF_E} \right) + \frac{a_h^i C_{iW}}{A_i''(h_i)} \left(\frac{dq_{iW}}{dF_E} + \frac{q_{iW}}{a_\phi^i C_{iW}} \frac{d\lambda_W}{dF_E} \right)$$

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

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Raising CAFE standards

- In regulating region, effects on FE decisions similar via increase in λ 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

Policy change in E	**No CAFE in W**	**CAFE in W**
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*.

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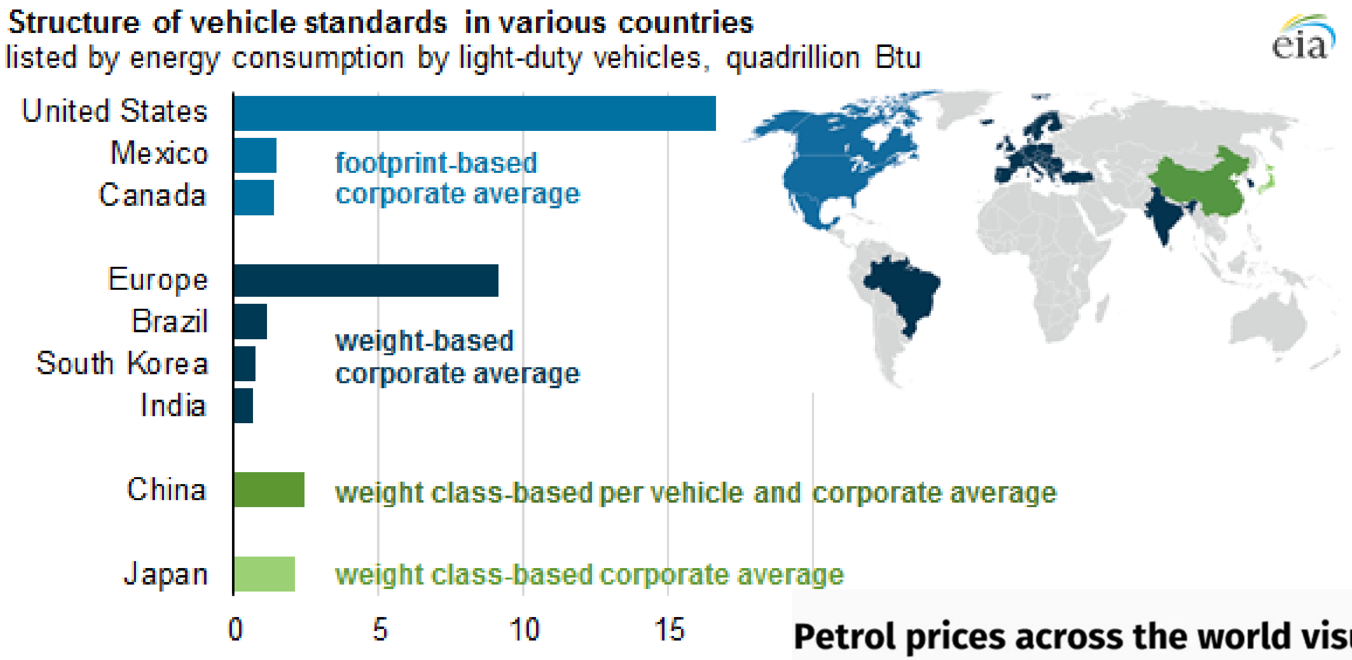
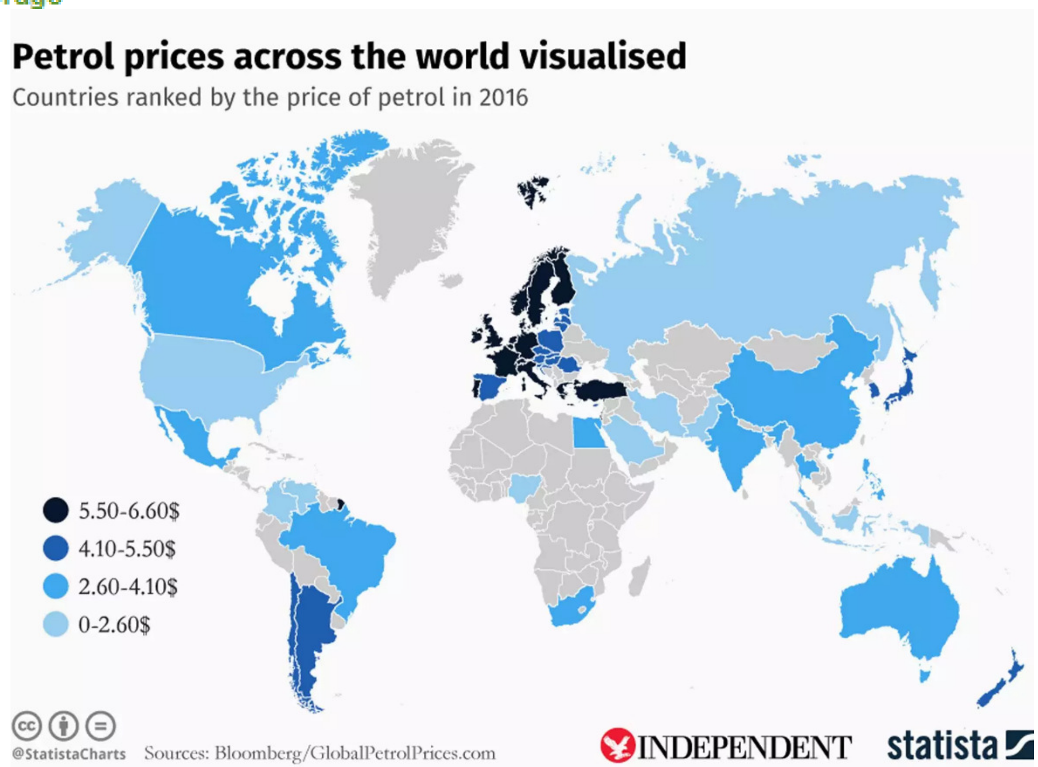
Predictions

- 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…



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Thanks!

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