Global Policy Spillovers:

How Environmental Policies Propagate through Product Attributes

Koichiro Ito[1] James M. Sallee[2] Andrew Smith[3]

[1]University of Chicago and NBER (ito@uchicago.edu)

[2]University of California, Berkeley and NBER

[3]University of Wisconsin–Madison

We would like to thank Caleb Halvorson-Fried, Linnea Holy and David Xu for their exceptional research assistance.

Motivation—Attribute propagation in global markets

- How should policymakers evaluate policy impacts when firms design products for global markets?
  - Standard economic analyses typically focus on domestic outcomes
  - However, multinational firms harmonize product design across markets
  - This creates the potential for policies implemented in one country to generate global spillovers through changes in product attributes

- We call this potential phenomenon "Attribute propagation"
  - Energy efficiency or emissions limits for cars, electric appliances, etc.
  - Safety regulations/standards that affect equipment, medications, etc.
  - Anti-trust measures determining product attributes

An example is the international car markets

- Automakers often sell common models in many countries
  - The world best selling models (Toyota Carolla, Rav4, Honda Civic, CR-V etc.) are sold in many countries
  - A country's environmental policy might affect these products worldwide

- Global spillover effects can be especially important in this context
  - A key outcome of environmental policy is global CO_2 emissions
  - Attribute propagation could enhance a policy's enviornmental impacts

What we do in this paper

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   - Fuel-economy subsidy in Japan improved fuel economy in the US market

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    - Estimate equilibrium effects from competition
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   - Spillover multiplier with equilibirum effects: 4.04
4. Conclusion: Attribute propagation is first-order
   - Abstracting from it could substantially understate the full policy impact

Related literature and our contributions

- Global spillover effects through different channels
  - Pollution havens (Levinson and Taylor 2008, Copeland 2008)
  - Used product movement (Davis and Kahn 2010, Tanaka, Teshima and Verhoogen 2022)
  - Innovation and learning-by-doing (Gerarden 2023, Barwick, Kwon, Li and Zahur 2024, Head, Mayer, Melitz and Yang 2025
  - Product entry (Sabal 2024)
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  - Our contribution: Attribute propagation is a distinct mechanism

- The closest is the "California effect" literature in political science
  - Vogel (1995,2020) coined "California effect" & "Brussels effect"
  - Insightful, but no empirical quantification
  - Our contribution: Provide causal evidence on attribute propagation & develop a framework to incorporate it into policy analysis

Outline

1. Introduction
2. Background
3. Difference-in-Differences Estimation
4. Structural Model
5. Counterfactual Policy Simulation
6. Conclusion

Background

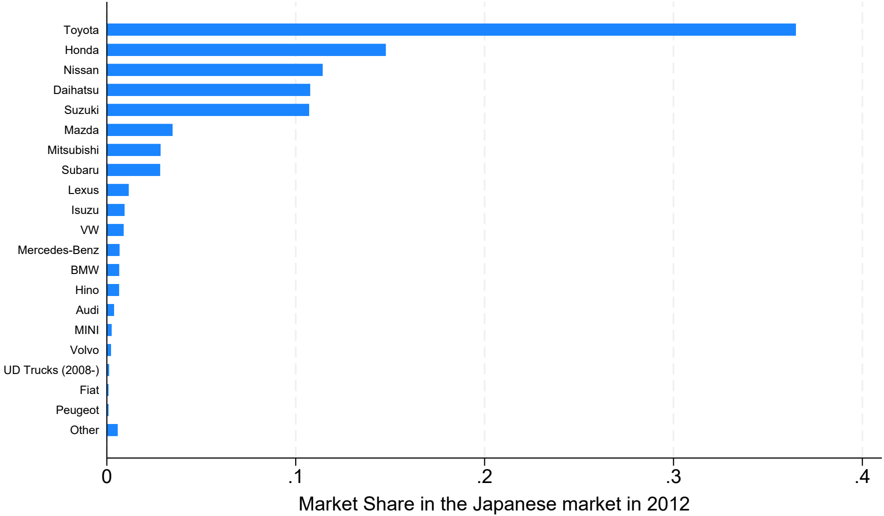
Policy: JPN government's subsidy for fuel-efficient vehicles

- "Eco-car" subsidy started in April, 2009
  - Consumers received a \$1,000 subsidy for a new car purchase if the model exceeds its 2015 fuel economy target
  - A stronger incentive for automakers to improve each model's fuel economy than the CAFE b/c the incentive was at the model level
  - Firms responded to it by improving fuel economy
- However, it was considered as an "expensive" policy
  - The government spent \$6.3 billion for the subsidy

Hypothesis: did the policy generate global spillovers?

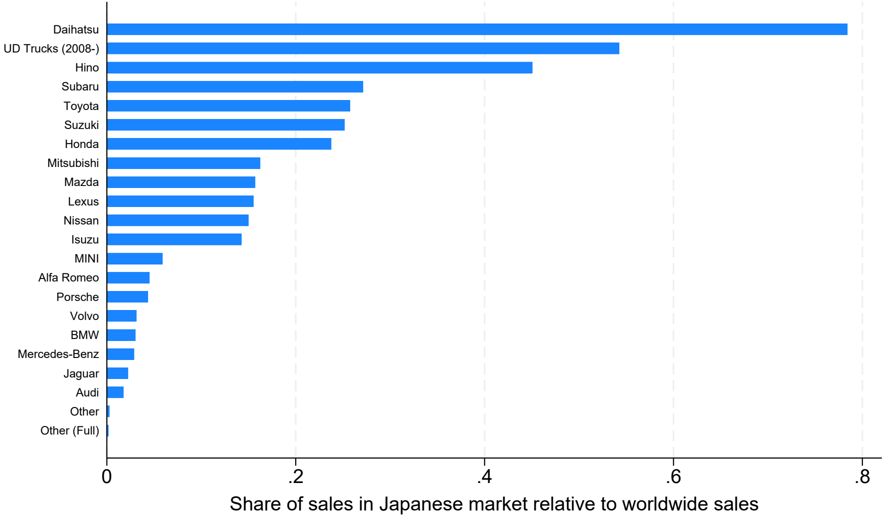
- What could be important factors for the potential spillover effect?
  - Firms face fixed costs of changing each model's product design
  - The subsidy incentive needs to be large enough to cover the fixed cost
- Conditions for home country:
  - The market has to be big enough for the model, otherwise it makes little sense for firms to respond to the subsidy's incentive
- Conditions for spillovered country:
  - Spillover impact is economically significant if the model's market share in the spillovered country is also larger

Which firms sell the most in the Japanese market?



- JPN firms dominate, European firms are second, and almost no American cars

Market share in Japan relative to a firm's worldwide sales



- JPN market is important for JPN & European firms, not so for American firms

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Difference-in-Differences Estimation

Identification strategy and data

- Identification strategy
  - Want to estimate JPN policy's impact on MPG of cars sold outside JPN
  - We use the difference-in-differences (DID) method
  - Time: before and after the policy introduction
  - Treated: models sold in home county (JPN) and spillovered country (US)
  - Control: the same firms' models sold in the US but NOT sold in JPN

- Data
  - Car characteristics data and sales data at the model level
  - Data sources: web-scraped car characteristics, sales from Marklines
  - Currently collected data for Japan, US, Germany, India
  - Linking models between countries is not obvious and needs careful work

Difference-in-differences for cars sold by JPN automakers

$$\ln e_{jt} = \alpha D_{jt} + \theta_j + \lambda_t + \delta X_{jt} + \epsilon_{jt},$$

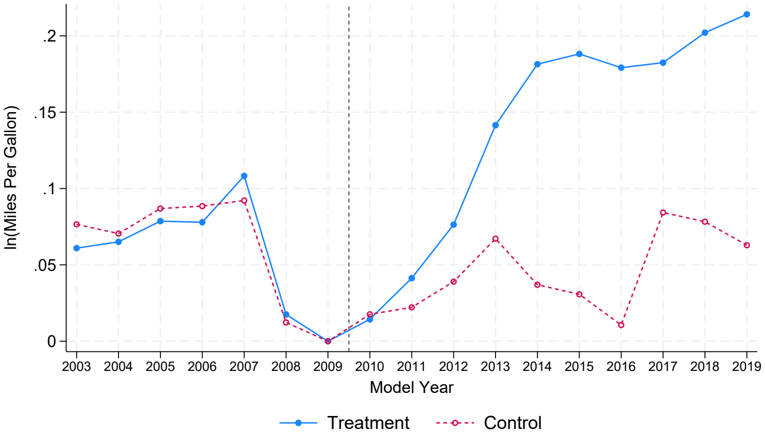
- Variables:
  - e_{jt}: Vehicle j's MPG (miles per gallon) in model year t in the US market
  - D_{jt}: Equals one if model j is sold in Japan and t is after the policy
  - θ_j: Model fixed effects
  - λ_t: Year fixed effects
  - X_{it}: Additional control variables (e.g, firm-specific year fixed effects)
  - Standard errors clustered at the model level to adjust for serial correlation

- Identification assumption:
  - Counterfactual parallel trends of MPG in the US between 1) models sold in both countries and 2) models not sold in Japan

1) Japanese cars in the US market

- US is the top 2 country in car sales (18.5% of the world sales)
- Japanese automakers have a 36.5% market share in the US

Average ln(MPG) in the US market: Weighted by sales



- Treated: Japanese cars sold in the US and Japan (90 models)
- Control: Japanese cars sold in the US but not in Japan (41 models)
- Vertical line: Introduction of the fuel-economy subsidy in Japan

Spillover effects for Japanese cars in the US market

$$\ln e_{jt} = \alpha D_{jt} + \theta_j + \lambda_t + \delta X_{jt} + \epsilon_{jt}$$

	(1)	(2)	(3)
Treated × Post	0.073	0.090	0.083
	(0.024)	(0.022)	(0.026)
N	9,098	9,098	9,098
Model FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Year × Truck FE	No	Yes	Yes
Year × Firm FE	No	No	Yes

- Subsidy in Japan increased fuel economy in US by 8.65% (0.083 log points)

Robustness Analysis of the DID Estimation

$$\ln e_{jt} = \alpha D_{jt} + \theta_j + \lambda_t + \delta X_{jt} + \epsilon_{jt}$$

	(1)	(2)	(3)	(4)
Treated × Post	0.097	0.105	0.106	0.071
	(0.028)	(0.030)	(0.031)	(0.026)
N	9,098	9,098	9,098	9,059
Model FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year FE × Truck FE	Yes	Yes	Yes	Yes
Year FE × Firm FE	Yes	Yes	Yes	Yes
Year FE × Higher-weight FE	Yes	No	Yes	Yes
Year FE × Higher-wheelbase FE	No	Yes	Yes	Yes
Year FE × Body-style FE	No	No	No	Yes

- The results are robust to these additional controls

2) American cars in the US market

- American automakers have a 45.1% market share in the US.
- American automakers have a 0.2% market share in Japan.

Spillover effects for American cars in the US market

$$\ln e_{jt} = \alpha D_{jt} + \theta_j + \lambda_t + \delta X_{jt} + \epsilon_{jt}$$

	(1)	(2)	(3)
Treated × Post	-0.027	-0.025	-0.068
	(0.030)	(0.028)	(0.029)
N	21,567	21,567	21,567
Model FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Year FE × Truck FE	No	Yes	Yes
Year FE × Firm FE	No	No	Yes

- Insignificant spillover effects
- Makes sense as American automakers have low market shares in Japan

3) Additional Robustness: Triple Difference Design

- Use American Vehicles as an additional control group
- This allows us to interact *Treated* with a various time fixed effects

Robustness Analysis Using Triple-Difference Estimation

	(1)	(2)	(3)
Treated × Post × Japanese Automakers	0.098	0.101	0.138
	(0.037)	(0.034)	(0.041)
Observations	30,665	30,665	30,665
Model FE	Yes	Yes	Yes
Year FE × Treated FE	Yes	Yes	Yes
Year FE × Treated FE × Truck FE	No	Yes	Yes
Year FE × Firm FE	No	No	Yes

- The results are robust to the triple difference estimation

(Supplementary results)
Japanese cars in the German market

- Germany is the top 5 country in car sales (3.9% of the world sales)
- Japanese automakers have a 9.8% market share in Germany

Spillover effects for Japanese cars in the German market

$$\ln MPG_{it} = \alpha Treated_i \times Post_t + \beta Treated_i + \gamma Post_t + \delta X_{it} + \epsilon_{it}$$

	(1)	(2)	(3)	(4)
Treated × Post	0.103	0.092	0.078	0.076
	(0.034)	(0.028)	(0.024)	(0.020)
Treated	-0.263	-0.263		
	(0.114)	(0.115)		
Post	0.044		0.047	
	(0.021)		(0.014)	
N	547	547	543	543
Year FE	No	Yes	No	Yes
Model FE	No	No	Yes	Yes

- Treatment: Japanese cars sold in Germany and Japan (84 models)
- Control: Japanese cars sold in Germany but not in Japan (7 models)
- Spillover effects: 8% increase in fuel economy

4) What Drives the Spillover Effects?

- Hypothesis 1: Model's production concentration may matter
  - Some models are produced in one location and shipped to many markets
  - Other models are produced separately for each market
  - Test if production concentration matters to spillover effects

- Hypothesis 2: Model's differentiation between markets may matter
  - Some models are almost exactly the same between markets
  - Other models are differentiated between markets
  - Test if pre-existing differentiation btw markets matters to spillover effects

What Drives the Spillover Effects?

Dependent variable: ln MPG_{jt}

	(1)	(2)	(3)
Treated × Post	0.083	0.096	0.108
	(0.021)	(0.025)	(0.023)
Treated × Post × Concentration of production locations	0.141		0.144
	(0.074)		(0.077)
Treated × Post × Differentiation across markets		-0.185	-0.194
		(0.074)	(0.073)
Observations	8,459	9,059	8,459

- More concentration of production location → larger spillover effects
- More differentiation between Japan and the U.S. → smaller spillover effects
  - Differentiation $= |ln(MPG_{j,JP,2008}) - ln(MPG_{j,US,2008})|$ in the pre-period
  - Concentration = Model's highest production in a single location divided by total production $\in (0, 1]$

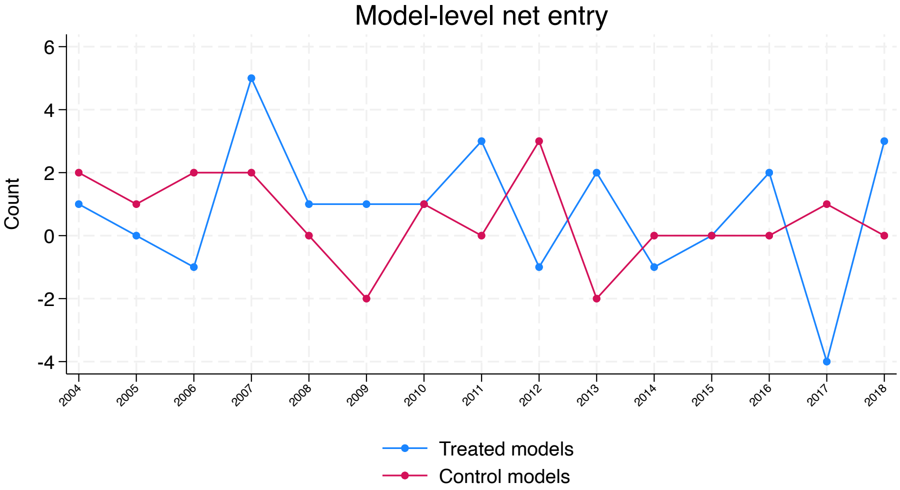
5) Potential additional spillover effects

- We test for the presence of additional spillover effects on:
  - Product entry/exit
  - Other product characteristics

- Findings:
  - Figure A1: No significant effects on product entry/exit
  - Table A2: No significant effects on other product attributes

→ The primary channel of spillover effects was fuel economy improvements

We do not find significant effects on product entry/exit



All Japanese models in the US car market.

We do not find significant effects on other attributes

	(1) MPG	(2) Horsepower	(3) Price	(4) Wheelbase	(5) Footprint	(6) Weight
Treated × Post	0.090	-0.077	-0.029	-0.009	-0.004	-0.019
	(0.022)	(0.037)	(0.025)	(0.008)	(0.010)	(0.021)
N	9,098	9,134	9,124	9,134	9,134	9,120

- Each column shows the DID result with each attribute as an outcome variable

6) Spillover “pass-through” rate

- How large was the spillover effects relative to the “domestic effects” of the policy in the home country?
- For the treated vehicles, we observe fuel economy in *Japan*
- We can therefore estimate the DID specification using fuel economy in Japan as the outcome variable for the treated vehicles

Domestic effects in Japan

	Dependent variable: ln MPG_{it}		
	(1)	(2)	(3)
Treated × Post	0.203	0.276	0.225
	(0.081)	(0.125)	(0.115)
N	12,812	12,810	12,810
Model FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Year × Truck FE	No	No	Yes
Year × Make FE	No	Yes	Yes

- Domestic effect: 25.2 percent (0.225 log points)
- Spillover pass-though rate = 0.34 (= 8.65 / 25.2)
- However, it does not mean environmental impact in the US was 0.34

7) Spillover Multiplier of Environmental Impacts

- A key policy-relevant outcome is ΔCO_2 emissions
- Δfuel-economy in the US can imply large total ΔCO_2 emissions
  1. U.S. automobile market is substantially larger than that of Japan
  2. U.S. drivers travel more miles per vehicle than Japanese drivers
- We quantity the spillover multiplier of environmental impacts (ρ):

$$\rho \equiv \frac{\text{Japanese policy's impacts on } CO_2 \text{ in Japan and the U.S.}}{\text{Japanese policy's impacts on } CO_2 \text{ in Japan}}$$

Spillover multiplier of environmental impacts (ρ)

$$\rho \equiv \frac{\text{Japanese policy's environmental impacts in Japan and the U.S.}}{\text{Japanese policy's environmental impacts in Japan}}$$

$$= 1 + \frac{\Delta\text{Externality per vehicle}_{US} \times Q_{US}}{\Delta\text{Externality per vehicle}_{JP} \times Q_{JP}}$$

$$= 1 + \frac{0.43 \text{ tons of } CO_2 \times 5,395,182}{0.24 \text{ tons of } CO_2 \times 2,074,181}$$

$$= 1 + \frac{2,351,186 \text{ tons of } CO_2 \text{ per year}}{493,443 \text{ tons of } CO_2 \text{ per year}}$$

$$= 5.42.$$

- Full policy impact on CO_2 emissions is 5.42 $\times$ the domestic effect
- Attribute propagation leads to a first-order policy impact

(Supplemental slide) Inputs to the calculation

- Sales quantify of the affected vehicles in the DID
  - The DID provides the ATET (ATE for the treated)
  - The treated vehicles are Japanese vehicles sold in both markets
  - $Q_{US} = 5,395,182$ and $Q_{JP} = 2,074,181$
- Average annual miles traveled per vehicle per year
  - 14,489 miles in the United States and 4,181 miles in Japan
- CO_2 emission per gallon of gasoline = 0.0088 (EPA's estimate)
- Potential rebound effects (drivers may drive more with better MPG)
  - Currently not incorporated but can be done
  - However, it will cancel out if it is similar in the two markets

What is potentially missing in ρ based on the DID results?

- The DID cannot capture potential equilibrium effects
  - Vehicles not directly affected by the global spillover may nevertheless adjust their fuel economy in response to competitors' changes
- We build a model of multinational car markets (next section)

Outline

A Model of Multinational Automobile Markets with Global Policy Spillovers

Overview of the model

1. Model and estimate a potential mechanism of global policy spillovers
   - Build on a standard differentiated-product market model (BLP, 1995)
   - Extend it to incorporate multinational markets
   - Extend it to incorporate firms' endogenous attribute choices
   - Model & estimate potential cross-market links in revenues and costs

2. Our model has two goals:
   - Estimate potential equilibrium effects to incorporate it into ρ
   - Investigate how cross-market links in revenues and costs could explain the mechanism of global policy spillover

Overview of the model

- Multinational firms maximize their profits in two countries
  - A home country where a policy intervention occurs (Japan in our case)
  - A spillovered country (United States in our case)

- Demand
  - A standard random-utility framework with random-coefficient logit
  - Consumer preferences are allowed to be different between countries
  - i.e. We estimate each country's demand system separately

- Supply
  - We consider a multinational multi-product firms that sell products $j \in J_f$
  - Marginal cost c_j is allowed to be different between countries
  - Firms also have fixed costs of improving fuel economy FC_j (Fang, 2013)
  - We allow FC_j to have cross-market complementarity

1) Demand—A random utility model for new car purchases

- p_{jc}: price for product j in market c
- x_{jc}: a vector of product characteristics for product j in market c

- Conditional indirect utility of consumer i who purchases product j

$$u_{ijc} = \beta_i x_{jc} + \alpha_i p_{jc} + \xi_{jc} + \epsilon_{ijc}$$

  - ξ_{jc}: unobserved factors at the market-product level
  - ϵ_{ijc}: unobserved factors at the market-product-consumer level (type-I extreme value)

1-1) Standard Logit Demand Approach

$$u_{ijc} = \beta_i x_{jc} + \alpha_i p_{jc} + \xi_{jc} + \epsilon_{ijc}$$

- First, assume that β and α do not depend on i
- The probability that consumer i in market c chooses product j is:

$$P_{ijc} = Pr(U_{ijc} > U_{ij'c}) \; \forall j' = \frac{\exp(\beta x_{jc} + \alpha p_{jc} + \xi_{jc})}{\sum_{j'=0}^{J} \exp(\beta x_{j'c} + \alpha p_{j'c} + \xi_{j'c})}$$

- Note that P_{ijc} does not depend on i. Then, the sum over i will be:

$$\sum_{i=1}^{N_c} P_{ijc} = N_c \cdot \frac{\exp(\beta x_{jc} + \alpha p_{jc} + \xi_{jc})}{\sum_{j'=0}^{J} \exp(\beta x_{j'c} + \alpha p_{j'c} + \xi_{j'c})}$$

1-1) Standard Logit Demand Approach

- The market share for product j in city c is:

$$s_{jc} \equiv \frac{1}{N_c} \sum_{i=1}^{N_c} P_{ijc} = \frac{\exp(\beta x_{jc} + \alpha p_{jc} + \xi_{jc})}{\sum_{j'=0}^{J} \exp(\beta x_{j'c} + \alpha p_{j'c} + \xi_{j'c})}$$

- The market share for the outside option S_{0c}
  - The outside option is not to buy product $j = 1, ..., J$
  - This market share is usually unobservable from a dataset
  - A typical approach is to assume that S_{0c} is the number of consumers (households) in market c that did not buy any product j
  - Consumers obtain zero utility if they do not purchase any of product j

$$s_{0c} = \frac{\exp(0)}{\sum_{j'=0}^{J} \exp(\beta x_{j'c} + \alpha p_{j'c} + \xi_{j'c})}$$

1-1) Standard Logit Demand Approach

- Log market share for j minus log market share for outside option:

$$\ln s_{jc} - \ln s_{0c} = \beta x_{jc} + \alpha p_{jc} + \xi_{jc}$$

- An advantage of this method is that it is just a linear equation
- An disadvantage is that it assumes restrictive substitution patterns: the Independence of Irrelevant Alternatives (IIA) assumption

1-2) Random Coefficient Logit Approach

- Allow heterogeneity in β and α by random-coefficients
- In this case, the market share for product j in country c becomes:

$$s_{jc} = \int \frac{\exp(\beta_i x_{jc} + \alpha_i p_{jc} + \xi_{jc})}{\sum_{j'=0}^{J} \exp(\beta_i x_{j'c} + \alpha_i p_{j'c} + \xi_{j'c})} f(\mu_i) d\mu_i,$$

- $f(\mu_i)$ is the distribution of random-coefficients (we use log-normal)

- Advantage: Allow for flexible substitution patterns, less restrictive price elasticity, and heterogeneous tastes

- Challenge: Non-linear GMM requires numerical simulation. Need careful implantation to obtain global optimal GMM estimates (Knittel and Metaxoglou 2013, Conlon and Gortmaker 2020)

2) Supply

- Multinational multi-product firm f's profit can be written by:

$$\text{Japan: } \pi_f = \sum_{j \in J_f} \left[\Big(p_j - c_j(e_j, x_j) \Big) \cdot q_j\big(p_j - \tau_j(e_j), e_j, x_j\big) \right]$$

$$\text{US: } \tilde{\pi}_f = \sum_{j \in \tilde{J}_f} \left[\Big(\tilde{p}_j - \tilde{c}_j(\tilde{e}_j, \tilde{x}_j) \Big) \cdot \tilde{q}_j\big(\tilde{p}_j, \tilde{e}_j, \tilde{x}_j\big) \right]$$

  - J_f: the set of cars sold by firm f
  - p_j: the price of car j
  - c_j: marginal cost
  - e_j: fuel economy
  - x_j: a vector of other attributes
  - q_j: demand
  - $\tau_j(e_j)$: the fuel-economy subsidy in Japan

- Firm f maximizes $\pi_f + \tilde{\pi}_f - \sum_j FC(e_j, \tilde{e}_j)$ w.r.t. $(p_j, e_j, \tilde{p}_j, \tilde{e}_j)$
  - $FC(e_j, \tilde{e}_j)$ is the fixed cost of improving fuel economy

Four types of first-order conditions

- FOC with respect to price and fuel economy in the US $(\tilde{p}_j, \tilde{e}_j)$:

$$\tilde{q}_j + \sum_{k \in \tilde{J}_f} \left[(\tilde{p}_k - \tilde{c}_k) \frac{\partial \tilde{q}_k}{\partial \tilde{p}_j} \right] = 0,$$

$$-\frac{\partial \tilde{c}_j}{\partial \tilde{e}_j} \tilde{q}_j + \sum_{k \in \tilde{J}_f} \left[(\tilde{p}_k - \tilde{c}_k) \frac{\partial \tilde{q}_k}{\partial \tilde{e}_j} \right] = \frac{\partial FC(e_j, \tilde{e}_j)}{\partial \tilde{e}_j},$$

- FOC with respect to price and fuel economy in the Japan (p_j, e_j):

$$q_j + \sum_{k \in J_f} \left[(p_k - c_k) \frac{\partial q_k}{\partial p_j} \right] = 0,$$

$$-\frac{\partial c_j}{\partial e_j} q_j + (p_j - c_j) \left(\frac{\partial q_j}{\partial e_j} - \frac{\partial q_j}{\partial (p_j - \tau_j)} \frac{\partial \tau_j}{\partial e_j} \right) + \sum_{k \neq j \in J_f} \left[(p_k - c_k) \frac{\partial q_k}{\partial e_j} \right] = \frac{\partial FC(e_j, \tilde{e}_j)}{\partial e_j}.$$

- We will describe how we use each equation in the next slides

2-1) Price FOCs $\rightarrow$ the estimation of the marginal cost

- Our approach builds on Berry, Levinson, and Pakes (1995)
- Firm's first order condition with respect to price (p_j) implies:

$$q_j + \sum_{k \in J_f} \left[\left(p_k - c_k(e_k, x_k) \right) \cdot \frac{\partial q_k}{\partial p_j} \right] = 0$$

- This equation and demand estimation provides us an estimate of c_k
- We regress c_k on attributes to estimate the marginal cost function

$$c_k = \beta_1 + \beta_2 e_j + \beta_3 x_j + \eta_j$$

- We estimate this separately for each country to allow heterogeneity

2-2) Fuel econ. FOCs → estimate the *slope* of fixed cost

- Our approach builds on Fan (2013) and Barwick, Kwon, and Li (2024)
- Firm's first order condition with respect to fuel economy (e_j) implies:

$$-\frac{\partial c_j}{\partial e_j} \cdot q_j + \sum_{k \in J_f} \left[\Big(p_k - c_k(e_k, x_k) \Big) \cdot \frac{\partial q_k}{\partial e_j} \right] = \frac{\partial FC(e_j, \tilde{e}_j)}{\partial e_j}$$

- LHS is the combination of data and demand/MC estimates
- This equation provides an estimate of the marginal fixed cost $\frac{\partial FC(e_j, \tilde{e}_j)}{\partial e_j}$
- Similarly, the FOC w.r.t. $\tilde{e}_j$ provides an estimate of $\frac{\partial FC(e_j, \tilde{e}_j)}{\partial \tilde{e}_j}$

2-2) Fuel econ. FOCs → estimate the *slope* of fixed cost

- Model the fixed cost function:

$$FC(e_j, \tilde{e}_j) = \gamma + (\gamma_0 e_j + \gamma_1 e_j^2) + (\tilde{\gamma}_0 \tilde{e}_j + \tilde{\gamma}_1 \tilde{e}_j^2) + \gamma_2 e_j \tilde{e}_j,$$

  - e_j: fuel economy in Japan
  - $\tilde{e}$: fuel economy in the US
  - γ_2 captures a potential cross-market complementarity
  - Hypothesis: $\gamma_2 < 0$ if there is a cross-market complementarity

- The derivatives with respect to e_j and $\tilde{e}_j$ imply:

$$\frac{\partial FC(e_j, \tilde{e}_j)}{\partial e_j} = \gamma_0 + 2\gamma_1 e_j + \gamma_2 \tilde{e} \quad (1)$$

$$\frac{\partial FC(e_j, \tilde{e}_j)}{\partial \tilde{e}_j} = \tilde{\gamma}_0 + 2\tilde{\gamma}_1 \tilde{e}_j + \gamma_2 e.$$

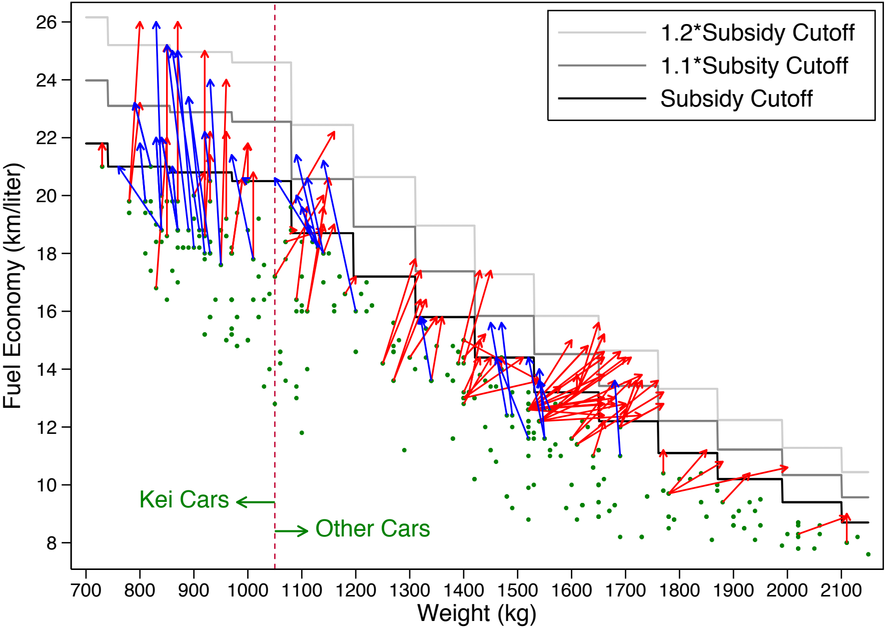
- We fit these equations to our data to estimate the parameters

Instruments

- Standard BLP considers that firms endogenously choose p_j only
  - BLP uses rivals' product characteristics as instruments for p_j

- In our model, we allow firms endogenously choose p_j and e_j
  - This means that we need an instrument for e_j
  - The instrument needs to be correlated with e_j
  - The instrument needs to be uncorrelated with the error terms

- We use a unique feature of the Japanese subsidy to create an IV
  - To be qualified for the subsidy, e_j needed to be above the target
  - The fuel-economy target was a non-linear step function (next page)
  - This created variation in easiness/difficulties to qualify for the subsidy
  - This variation created a policy-induced change in e_j in policy period
  - Recall that the subsidy was introduced in 2009
  - We create $\tilde{\Delta} e_j = e_j^{\text{target}} - e_{j,2008}$ as an instrument for e_j

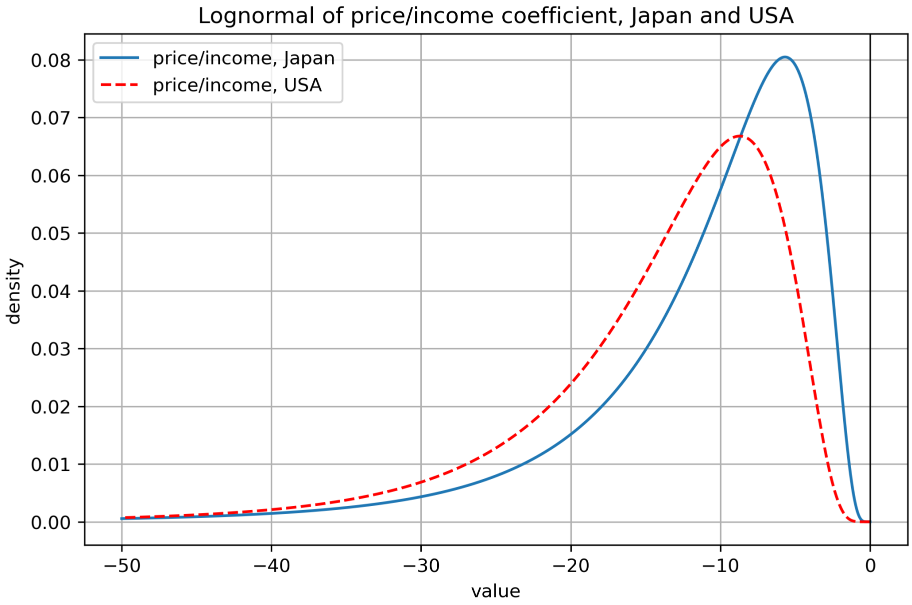


- This figure is from Ito and Sallee (2018)

1) Demand estimation results

	(1)	(2)
	Japan	US
Fuel economy (Miles per gallon)	0.117	0.244
	(0.009)	(0.032)
Horsepower	0.011	0.021
	(0.002)	(0.004)
Vehicle weight (1,000kg)	3.510	2.617
	(0.308)	(0.282)
Price/income (USD): Median coefficient	-18.50	-17.36
	(6.86)	(4.90)
Random-coefficient π	2.918	2.854
	(0.371)	(0.304)
Random-coefficient σ	1.079	0.641
	(0.190)	(0.093)
Observations	2142	1469

- Sigma is the standard deviation for the log-normal random-coefficient for price



Lognormal of price/income coefficient, Japan and USA
price/income, Japan
price/income, USA
density
value
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−50
−40
−30
−20
−10
0

2) Marginal cost estimation results

	Japan		US	
	(1)	(2)	(3)	(4)
Fuel economy (MPG)	314.89	416.56	926.83	703.99
	(15.79)	(16.82)	(96.41)	(67.46)
Horsepower	200.64	111.97	131.50	85.13
	(5.08)	(4.85)	(4.60)	(3.49)
Vehicle weight (kg)	5.68	14.97	13.26	12.47
	(0.74)	(0.68)	(1.11)	(0.84)
Firm FE	No	Yes	No	Yes
Observations	2142	2142	1469	1469

- Costs are in USD, and fuel economy (e_j) is in miles per gallon

3) *Slope* of fixed cost estimation results

	(1)	(2)	(3)	(4)
γ_1	0.897	0.853	1.149	0.816
	(0.040)	(0.080)	(0.077)	(0.086)
γ_2	-0.217	-0.321	-0.482	-0.236
	(0.041)	(0.076)	(0.081)	(0.077)
$\gamma_2 \times$ Concentration of production locations			-2.388	-1.193
			(0.279)	(0.245)
Country FE	Yes	Yes	Yes	Yes
Firm FE $\times$ Country FE	No	Yes	No	Yes

- $\gamma_2 < 0$ suggests the empirical evidence of cross-market complementarity
- Interaction term: Cross-market complementarity is larger for models with higher concentration of production locations
- The monetary unit is one million USD. The unit of e_j is miles/gallon.

Outline

Counterfactual Policy Simulation

Counterfactual policy simulation

- Use our model and estimates to run counterfactual policy simulations
- What if Japan *did not* implement the fuel-economy subsidy?
  - Lowers demand for fuel-efficient cars in Japan
  - Lowers incentives for firms to improve fuel-economy
  - Lowers fuel-economy in US through cross-market link in the fixed cost
  - Potential equilibrium effects: unaffected vehicles may change p_j and e_j
  - Use the model to compute the new equilibrium of $(p_j, e_j, \tilde{p}_j, \tilde{e}_j)$
- We use our model to simulate two scenarios:
  - Actual scenario (with the fuel-economy subsidy in Japan)
  - Counterfactual scenario (remove the fuel-economy subsidy in Japan)
  - Quantify the Japanese policy's global spillover effects on the US market

Panel A: Average fuel consumption (gallons per 100 miles)

	Actual	Counterfactual (no subsidy in Japan)	Impacts of the subsidy	
			Levels	% changes
Japan: All vehicles	2.27	2.61	-0.34	-13.02
Japan: Subsidized vehicles	1.93	2.47	-0.54	-21.86
Japan: Other vehicles	3.01	2.91	0.10	3.39
US: All vehicles	4.13	4.28	-0.14	-3.36
US: Spillovered vehicles	3.74	4.04	-0.30	-7.45
US: Other vehicles	4.25	4.35	-0.10	-2.21

Panel B: CO_2 emissions reductions (megatonnes/year) and spillover multiplier (ρ)

Emissions reductions in Japan	Emissions reductions in the US	Spillover multiplier (ρ)
0.75	2.27	4.04

- Affected vehicles: Effects are consistent with our results based on the DID
- Unaffected vehicles: Equilibrium effects are smaller but important
- Spillover multiplier: Majority of policy-induced ΔCO_2 comes from US market

Conclusion

What we do in this paper

1. Difference-in-differences (DID) design
   - Fuel-economy subsidy in Japan improved fuel economy in the US market

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4. Conclusion: Attribute propagation is first-order
   - Abstracting from it could substantially understate the full policy impact

Thank you!

ito@uchicago.edu

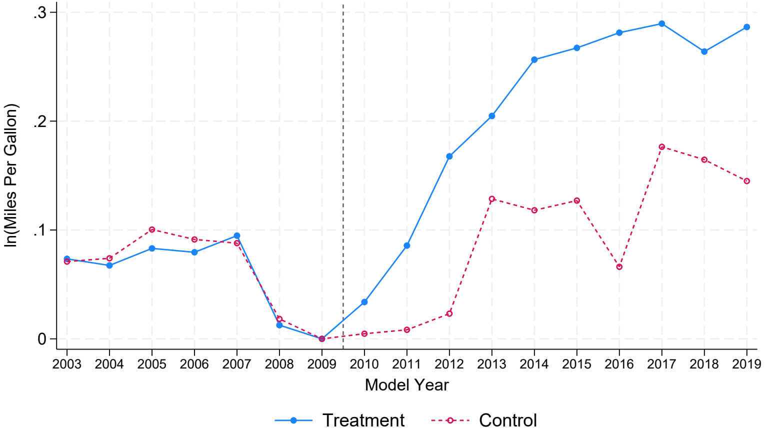
Appendix

Baseline characteristics in the pre-subsidy period

	Treated		Control		Difference		Adjusted Difference	
	Mean	S.D.	Mean	S.D.	Mean	S.E.	Mean	S.E.
Price (1,000 USD)	24.1	(7.8)	28.1	(7.7)	-4.0	(2.0)	-0.7	(1.9)
Miles per gallon	25.7	(5.5)	18.9	(3.8)	6.8	(1.3)	1.4	(1.1)
Horsepower	187.2	(57.0)	237.3	(55.3)	-50.0	(15.5)	-13.6	(13.1)
Length (feet)	15.3	(0.7)	16.6	(1.5)	-1.4	(0.4)	-0.2	(0.2)
Width (feet)	5.9	(0.2)	6.3	(0.3)	-0.4	(0.1)	-0.1	(0.1)
Height (feet)	5.1	(0.4)	5.8	(0.4)	-0.7	(0.1)	-0.1	(0.1)
Wheelbase (feet)	8.9	(0.4)	10.0	(1.3)	-1.1	(0.3)	-0.1	(0.1)
Footprint (square feet)	52.6	(3.6)	62.7	(10.1)	-10.1	(2.7)	-1.5	(1.2)
Weight (1,000 lbs)	3.3	(0.5)	4.2	(0.8)	-0.9	(0.2)	-0.2	(0.2)

- "Adjusted difference" column reports differences in means controlling for body-type fixed effects (sedan, hatchback, wagon, coupe, convertible, SUV, crossover, pickup truck, and van)
- Observable characteristics are similar between the two groups once we control for body types

Average ln(MPG) in the US market: Unweighted



- Treated: Japanese cars sold in the US and Japan (90 models)
- Control: Japanese cars sold in the US but not in Japan (41 models)
- Vertical line: Introduction of the fuel-economy subsidy in Japan

Japanese cars in the German market

- Germany is the top 5 country in car sales (3.9% of the world sales)
- Japanese automakers have a 9.8% market share in Germany

Spillover effects for Japanese cars in the German market

$$\ln MPG_{it} = \alpha Treated_i \times Post_t + \beta Treated_i + \gamma Post_t + \delta X_{it} + \epsilon_{it}$$

	(1)	(2)	(3)	(4)
Treated × Post	0.083	0.076	0.078	0.076
	(0.035)	(0.031)	(0.024)	(0.020)
Treated	-0.263	-0.263		
	(0.114)	(0.115)		
Post	0.061		0.047	
	(0.022)		(0.014)	
N	547	547	543	543
Year FE	No	Yes	No	Yes
Model FE	No	No	Yes	Yes

- Treatment: Japanese cars sold in Germany and Japan (84 models)
- Control: Japanese cars sold in Germany but not in Japan (7 models)
- Spillover effects: 8% increase in fuel economy

Japanese cars in the Indian market

- India is the top 4 country in car sales (4.6% of the world sales)
- Japanese automakers have a 49.2% market share in India

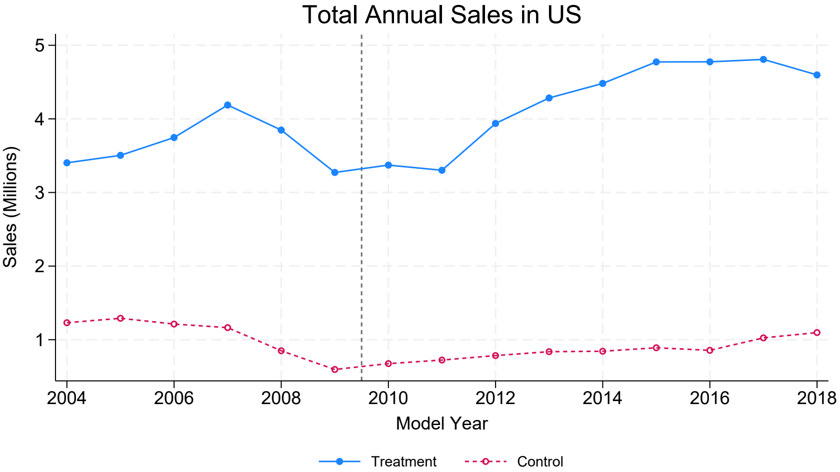
Spillover effects for Japanese cars in the Indian market

$$\ln MPG_{it} = \alpha Treated_i \times Post_t + \beta Treated_i + \gamma Post_t + \delta X_{it} + \epsilon_{it}$$

	(1)	(2)	(3)	(4)
Treated × Post	0.173	0.144	0.285	0.272
	(0.135)	(0.142)	(0.056)	(0.060)
Treated	-0.016	-0.016		
	(0.139)	(0.143)		
Post	0.115		-0.006	
	(0.123)		(0.009)	
N	147	147	145	145
Year FE	No	Yes	No	Yes
Model FE	No	No	Yes	Yes

- Treatment: Japanese cars sold in India and Japan (29 models)
- Control: Japanese cars sold in the India but not in Japan (13 models)

Sales over time



- Electricity is a major source of GHG emissions (e.g., 25% in the US)
- Another large source is transportation, which can be electrified soon

Spillover effects for Japanese cars in the US market (Unweighted)

$$\ln MPG_{it} = \alpha Treated_i \times Post_t + \beta Treated_i + \gamma Post_t + \delta X_{it} + \epsilon_{it}$$

	(1)	(2)	(3)	(4)
Treated × Post	0.118	0.114	0.063	0.061
	(0.061)	(0.059)	(0.017)	(0.016)
Treated	0.216	0.217		
	(0.043)	(0.043)		
Post	0.053		0.013	
	(0.050)		(0.013)	
N	1,245	1,245	1,238	1,238
Year FE	No	Yes	No	Yes
Model FE	No	No	Yes	Yes

- Spillover effects: 6∼11% increase in fuel economy

JPN cars in Germany market (Control: US)

	(1)	(2)	(3)	(4)
Treated × Post	0.147	0.112	0.115	0.081
	(0.046)	(0.040)	(0.025)	(0.023)
Treated	0.595	0.628	-0.106	-0.080
	(0.062)	(0.056)	(0.022)	(0.020)
Post	-0.003		0.010	
	(0.037)		(0.017)	
N	793	793	790	790
Year FE	No	Yes	No	Yes
Model FE	No	No	Yes	Yes

- Treatment: Japanese cars sold in Germany and Japan (84 models)
- Control: Japanese cars sold in the US but not in Japan (41 models)

JPN cars in India market (Control: US)

	(1)	(2)	(3)	(4)
Treated × Post	0.382	0.365	0.319	0.286
	(0.050)	(0.050)	(0.035)	(0.031)
Treated	0.481	0.491	-0.107	-0.042
	(0.066)	(0.069)	(0.028)	(0.029)
Post	-0.016		0.010	
	(0.036)		(0.017)	
N	424	424	423	423
Year FE	No	Yes	No	Yes
Model FE	No	No	Yes	Yes

- Treatment: Japanese cars sold in India and Japan (29 models)
- Control: Japanese cars sold in the US but not in Japan (41 models)

European cars in the US market

- European automakers have a 8.5% market share in the US.
- European automakers have a 4.6% market share in Japan.

Spillover effects for European cars in the US market

$$\ln MPG_{it} = \alpha Treated_i \times Post_t + \beta Treated_i + \gamma Post_t + \delta X_{it} + \epsilon_{it}$$

	(1)	(2)	(3)	(4)
Treated × Post	0.069	0.072	0.108	0.095
	(0.049)	(0.052)	(0.016)	(0.022)
Treated	-0.151	-0.153		
	(0.075)	(0.074)		
Post	0.055		0.009	
	(0.045)		(0.012)	
N	962	962	959	959
Year FE	No	Yes	No	Yes
Model FE	No	No	Yes	Yes

- Treatment: EU cars sold in the US and Japan (95 models)
- Control: EU cars sold in the US but not in Japan (43 models)