Estimating the Rebound Effect: A Quasi-experiment with Hybrid Pairs

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The Rebound Effect

- Gains in efficiency induce increased use.
- Fuel efficiency $\uparrow \Rightarrow$ cost per mile of driving $\downarrow \Rightarrow$ people are incentivized to drive more.
- Rebound effect implies that increased fuel efficiency does not result in proportional decrease in fuel consumption.
- Typically quantified as elasticity of vehicle miles traveled (VMT) w.r.t. cost per mile (CPM):

$$\varepsilon \approx \frac{\%\Delta VMT}{\%\Delta CPM}$$

Key Goals

- Investigate the utilization ("rebound") effects of the Corporate Average Fuel Economy (CAFE) standards.
  - Established minimum average fuel efficiency requirements for a manufacturer's fleet.
  - Set to increase substantially.
- Provide evidence about effectiveness of the CAFE standards in reducing energy use.

Key Goals

- Rely on a quasi-experiment with hybrid pairs.
- Compare VMT for hybrids vs. non-hybrids and compute the elasticity of VMT with respect to CPM.
- Use propensity score matching to mitigate selection bias.
  - Households that tend to drive often may be more likely to purchase a hybrid.
  - Match households on predicted probability of choosing a hybrid.

Contribution

- Uses disaggregated data at the household level.
- Utilizes hybrid pairs.
  - Comparing choices between e.g. Honda Civic and Honda Civic Hybrid holds many vehicle attributes fixed.
  - Mitigates problems with unobserved vehicle attributes and endogeneity in the vehicle choice model.
- Implements a partially observed vehicle choice model.
  - Extends work of Brownstone, D., Kim, J., and Wang, J. (2011) and Wang (2011).

Data

- Household Data: 2009 National Household Transportation Survey (NHTS).
  - NHTS does not indicate trimline of the household vehicle.
  - Not sufficient to match vehicle attributes, such as price.

Figure: Vehicle Specifications for 2009 Honda Civic from Ward's

Make & Series	Body Style	Drive Type	Length (ins.)	Width (ins.)	Weight (lbs.)	Horsepower		Trans Std.	MPG City/Hwy	Retail Price
						Hp	@RPM			
Hybrid	4-dr. sedan	FWD	177.3	69.0	2,875	110	6000	CVT	40/45	$24,320
Civic DX	4-dr. sedan	FWD	177.3	69.0	2,630	140	6300	M5	26/34	$16,175
Civic LX	4-dr. sedan	FWD	177.3	69.0	2,687	140	6300	M5	26/34	$18,125
Civic EX	4-dr. sedan	FWD	177.3	69.0	2,747	140	6300	M5	26/34	$19,975

Vehicle counts for hybrid pairs in the NHTS

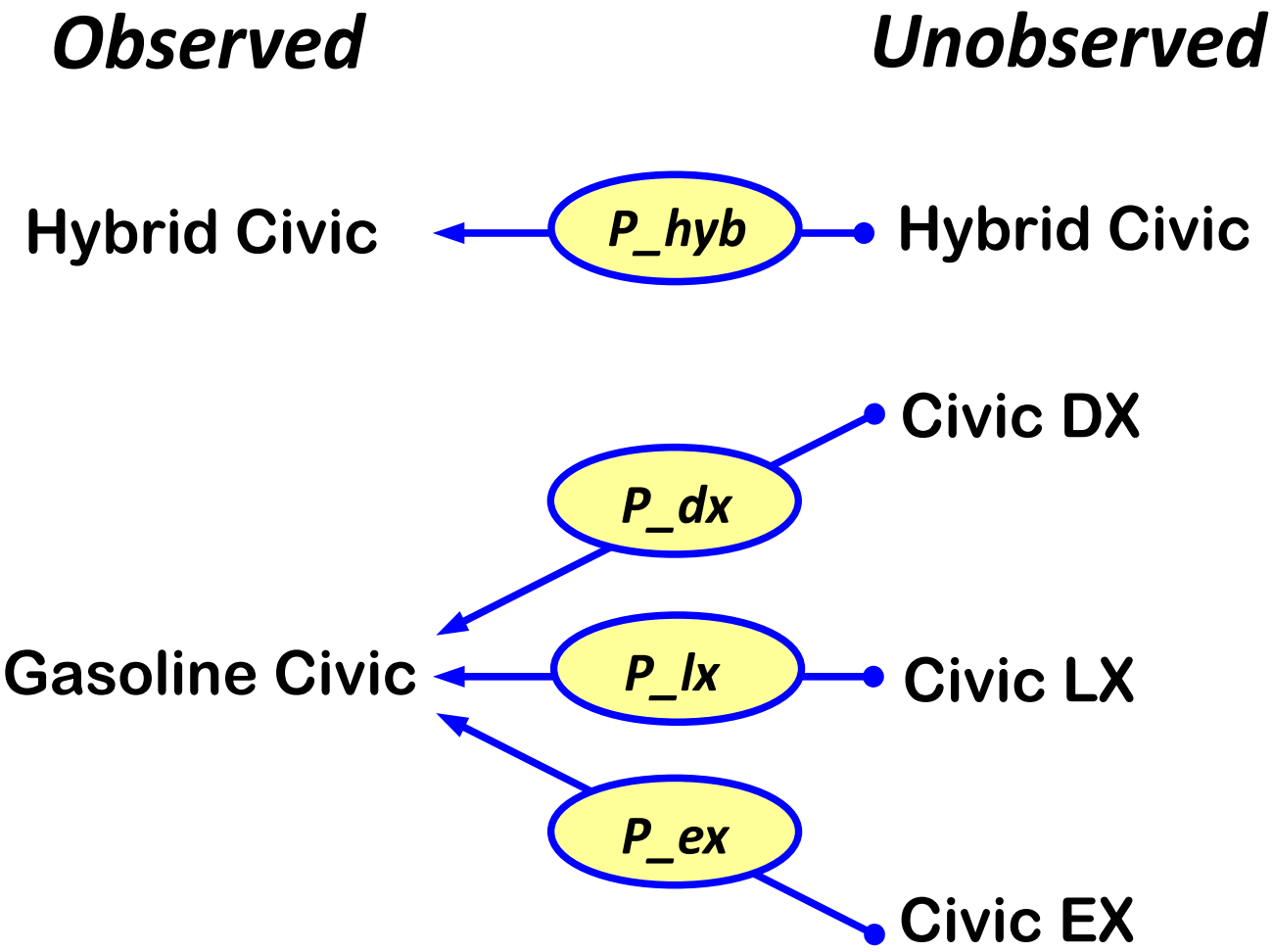
	Non-hybrid	Hybrid	Total
Ford Escape	577	107	684
Mercury Mariner	78	21	99
Cadillac Escalade	2	0	2
Chevrolet Tahoe	1	1	2
Chevrolet Silverado	9	8	17
GMC Yukon	2	1	3
Saturn Aura	61	0	61
Saturn Vue	4	0	4
Nissan Altima	24	2	26
Honda Civic	1180	229	1409
Honda Accord	510	17	527
Mazda Tribute	1	0	1
Toyota Camry	1212	250	1462
Toyota Highlander	422	153	575
Lexus LS	28	5	33
Lexus GS	32	7	39
Lexus RX	251	57	308
Total	4394	858	5252

Estimation Strategy: Propensity Score Matching

- Implement Propensity Score Matching to account for any selection bias.
- Key Assumption: conditional on exogenous attributes, choice between hybrid and non-hybrids is independent of miles driven.
- Match households on their estimated probability of buying a hybrid (propensity score).
  - Sort households into bins according to propensity score.
  - Compute the average elasticity of vehicle miles traveled with respect to cost per mile for the matched households.
  - Compute a weighted average across all households.

Estimation Strategy: Partially Observed Choice Model

- To perform PSM, need to predict each household's probability of buying a hybrid.
- Rely on a nested structure.
  - Household chooses a vehicle make and model, and then the hybrid or non-hybrid variant.
  - Estimate bottom level of the hierarchy.
- Treat household vehicle as partially observed: only observe if the household chooses a hybrid or non-hybrid.



Probability household chooses a gasoline civic: $P_{dx} + P_{lx} + P_{ex}$

Partially Observed Vehicle Choice Model Continued

- Under standard multinomial logit model, probability of household i choosing vehicle p:

$$\Pr_{ip} = \frac{e^{x'_{ip}\beta}}{\sum_j^J e^{x'_{ij}\beta}}$$

where x is a vector of covariates and J represents the total number of alternatives.

Partially Observed Vehicle Choice Model Continued

- Probability of observing a hybrid is given by the sum of the multinomial probabilities for each hybrid alternative.

$$\Pr(y_i = 1|\beta) = \sum_{h=1}^{H} \frac{e^{x'_{ih}\beta}}{\sum_j^J e^{x'_{ij}\beta}}$$

  where H represents the number of hybrid alternatives.

- Probability of observing a non-hybrid is given by the sum of the multinomial probabilities for each non-hybrid alternative, or simply $1 - \Pr(y_i = 1|\beta)$.

Partially Observed Vehicle Choice Model Continued

- Likelihood contribution for household, i is then,

$$f(y_i|\beta) = \Pr(y_i = 1|\beta)^{y_i}(1 - \Pr(y_i = 1|\beta))^{1-y_i}$$

- Likelihood function follows as,

$$L(\beta; y) = \prod_{i}^{n} \Pr(y_i = 1|\beta)^{y_i}(1 - \Pr(y_i = 1|\beta))^{1-y_i}$$

- Log likelihood is given by

$$\mathcal{L}(\beta; y) = \sum_{i}^{n} y_i \ln(Pr(y_i = 1|\beta)) + (1-y_i) \ln(1-\Pr(y_i = 1|\beta))$$

Coefficient Estimates: Partially Observed Choice Model

	Civic, Camry, Accord	
(price-fedTax)/income	-1.241	(0.542)
(price-fedTax)×college	-2.653	(0.487)
horsepower/weight	25.058	(5.121)
operating cost	-0.127	(0.033)
hyb×college	1.478	(0.235)
hybrid	-1.009	(0.228)
hyb×urban	-0.011	(0.117)
hyb×stateTax	0.275	(0.103)
hyb×2AdItsChld0to5	-0.150	(0.189)
hyb×1AdItChld6to15	0.538	(0.425)
hyb×2AdItsChld6to15	-0.096	(0.150)
hyb×2AdItsChld16to21	-0.698	(0.223)
hyb×1AdItRetired	-0.835	(0.296)
hyb×2AdItsRetired	-0.085	(0.131)
hyb×distToWork	0.035	(0.025)

Willingness to Pay

Table: Willingness to pay estimates for a one cent per mile (on average $130 a year) reduction in operating cost with standard errors in parentheses.

Household Income		
	No College	
$47,500	4866	(2574)
$77,500	7940	(4199)
$120,000	12294	(6502)
	College	
$47,500	436	(152)
$77,500	452	(158)
$120,000	461	(163)

Results: Rebound Effect and Induced Demand for VMT

Table: Propensity score matching estimates for the rebound effect with standard errors in parentheses.

	Civic			*Camry*		
# of Bins	4	14	21	5	9	20
ΔVMT	1214	1150	1300	1337	1111	1522
	(710)	(573)	(487)	(1139)	(986)	(1509)
Elasticity	-0.230	-0.293	-0.265	-0.262	-0.214	-0.369
	(0.135)	(0.150)	(0.118)	(0.217)	(0.172)	(0.293)