Household Diversification: The Vehicle Portfolio Effect

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Question

When households have more than one of a good, to what extent do the attributes of one item affect the desired attributes of another?

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- Typical demand systems assume away multi-product nature of households' portfolios
- E.g. Cars. It is common to assume households buy only one vehicle, or that each vehicle choice is independent of others
  - Goldberg 1995 & 1998, BLP 1995 & 2004, Schiraldi 2011, Jacobsen 2013, Allcott & Wozny 2014, etc.

Policy Relevance

If there are portfolio interactions

- Single good purchase models using microdata may be biased, affecting:
  - Price elasticities of demand
  - Consumer welfare
  - Firm strategy
  - Net external costs associated with the good's consumption or use
  - Policy evaluation
  - etc.

Intellectual Anticedents

Household preference for diversification

- Cars (Wakamori 2015)
- Media consumption (Gentzkow 2007)
- Gender diversity in children (Ben-Porath & Welch 1976, Angrist & Evans 1998)
- Household members adopt multiple livelihood strategies (Ellis 2000)

Policy Relevance: Fuel Economy Standards

Recall drawbacks of fuel economy standards for GHG abatement

- Some gasoline-powered vehicles are implicitly subsidized
- Reduces cost per km traveled ("rebound effect")
- Exposed to potential gaming (Reynaert & Sallee WP)
- Extends lifecycle of used, fuel-inefficient vehicles by eliminating newer substitutes (Jacobsen & Van Benthem 2015)

Today we explore another potential channel.

Simple Theory Framework

Goal: fix ideas and motivate empirics

- Incorporate portfolio interactions as in Gentzkow (2007) & Wakamori (2015)
- Allow goods in household portfolio to be substitutes or complements
  - Print : online media
  - "Kei" cars : sedans : mini-vans
  - Our setting: fuel efficiency : other car attributes (fuel economy, power, size, etc)

Model

- Random utility discrete choice model
- Consider a 1-car household that has decided to buy a second car

Simple Theory Framework

Utility:

$$u_{i,AB} = f(\theta_A) + f(\theta_B) + \Gamma_{AB} - \alpha(p_{A1} + p_{B2}) + \epsilon_{i,AB}$$

where

- θ_V is a vector of vehicle characteristic of vehicle type $V \in \{A, B, ...\}$
- Γ_{V_1,V_2}: contribution to utility from diversity of the portfolio
- p_{Vj} remaining "PV lifetime ownership cost" for a vehicle of type V
  - Includes gasoline & maintenance
- $j \in \{1, 2\}$ reflects order of vehicle entry into household portfolio
- α is the marginal utility of money

Empirical Goal: Estimate equilibrium effect of θ_A on θ_B

Simple Theory Framework

WLOG, normalize $\Gamma_{AA} = 0$.

Choose a diversified portfolio if:

$$\Gamma_{AB} > f(\theta_A) - f(\theta_B) + \alpha(p_{B2} - p_{A2})$$

Simple Theory Framework

Implications of an **increase in the price of gasoline**:

- Direct Effect: The probability of the choosing the higher fuel economy vehicle will increase.
- Indirect Effect: Equilibrium relative prices of cars will change, so that higher fuel economy vehicles will increase in price relative to others.

Implications:

- Either effect may dominate
- New vs used car market differences in GE

Simple Theory Framework

Implications for **fuel economy standard**:

- FE standards create a fleet-wide weighted average GPM requirement for new car sales
- Changes relative prices
  - Tax (new) gas guzzlers, subsidize (new) fuel efficient
  - Used car market responds in GE
- If HHs exhibit portfolio interactions across cars, FE standards may be less effective

Data Sources

- Universe of CA residential DMV records, 2001-2007
  - Household IDs, VINs, registration date
- VMT (Smog Check)
- VIN decoder (DataOne)
- Gasoline prices (OPIS)

Household Portfolio Transitions

Start Portfolio Size	End Portfolio Size 1	2	3	4+
1	7,262,111	1,360,594	187,558	75,150
2	1,172,278	4,632,425	839,546	259,098
3	168,745	849,703	2,169,948	675,040
4+	35,810	141,618	381,226	1,489,926

Identification: Thought Exercise

1. Consider a 2-car household
2. Randomly drop one
3. Randomly perturb the the fuel intensity (GPM) of the kept car
4. What effect does this have on the choice of fuel intensity of the bought car?

Thought Exercise

Starting Portfolio

Ending Portfolio

Thought Exercise

Starting Portfolio

Kept Car

Ending Portfolio

Thought Exercise

Starting Portfolio

Ending Portfolio

Kept Car

Thought Exercise

Starting Portfolio

Ending Portfolio

Kept Car

Bought Car?

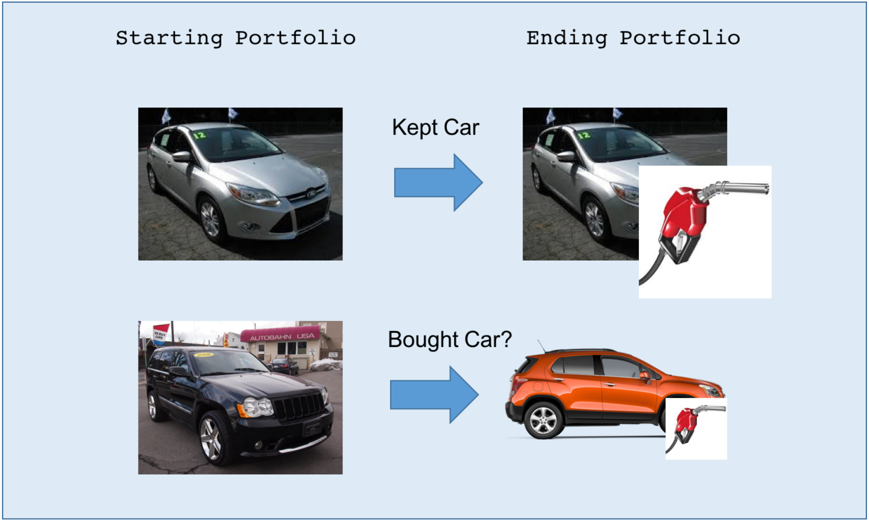
Thought Exercise

Starting Portfolio

Ending Portfolio

Kept Car

Thought Exercise



Base Specification

$$
\begin{aligned}
f^b_{it} = \quad & \beta_0 + \beta_g p^{gas}_{it} + \mathbb{1}^{k>d} + \mathbb{1}^{k>d}_{it} \times \left(\beta_{fk} f^k_{it} + \beta_{gfk} p^{gas}_{it} \times f^k_{it}\right) + \\
& \mathbb{1}^{d \geq k}_{it} \times \left(\beta_{fd} f^k_{it} + \beta_{gfd} p^{gas}_{it} \times f^k_{it}\right) + \alpha_X X^k_{it} + \varepsilon_{it}
\end{aligned}
$$

where

- f^b_{it} and f^k_{it}: fuel intensity of the bought and kept cars (GPM)
- p^{gas}_{it}: i's gas price at date t
- X_{it}:
    - vehicle attributes (e.g. class, make, value, age)
    - nonparametric time controls (year and month-of-year fixed effects) and
    - household/demographic (household fixed effects and county-level unemployment).

Identification: Two Sources of Endogeneity

1. Endogenous selection of which car to drop/sell
    - Contrary to exogeneity required in our thought experiment
2. Preferences (potentially time-varying) over unobserved product attributes of the kept car
    - This is the canonical demand system problem addressed by BLP and others
    - We take a non-structural approach

Identification: Solutions

Regression controls and two instrumental variables

- Household fixed effects
  - Examine patterns *within* households with multiple purchases
- IV1: Functions of price differences between kept and dropped cars
  - These are correlated with which car is dropped
  - Plausibly exogenous
- IV2: Gasoline prices at time of kept and dropped car purchase
  - Many papers have shown that purchase behavior is influenced by contemporaneous gasoline prices (Klier & Linn (2010), Busse, Knittel & Zettelmeyer (2013), Gillingham (2011), etc)
  - Long-past gasoline prices should not influence present car choice

A potential asymmetry

- Relative fuel intensity of the kept-to-dropped car may be endogenous to HH preferences
- Our estimates allow for this asymmetry
- Let f^k and f^d denote fuel intensity in gallons per mile (GPM) of the kept and dropped car in a 2-car household that replaces one car
- Define:

$$\mathbb{1}^{k>d} \equiv \mathbb{1}\{f^k > f^d\}$$
$$\mathbb{1}^{d\geq k} \equiv \mathbb{1}\{f^d \geq f^k\} = \left(1 - \mathbb{1}^{k>d}\right)$$

IV1: Price differences

Hypothesis: relative asset value influences choice of car to keep/drop

- Candidate 1: Price difference at time of drop
  - $\Delta P_{it}^{kd} = P_{it}^{k} - P_{it}^{d}$

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- Candidate 2: Difference in price difference relative to time of kept car purchase
  - $\Delta\Delta P_{it}^{kd} = (P_{it}^{k} - P_{i0}^{k}) - (P_{it}^{d} - P_{i0}^{d})$

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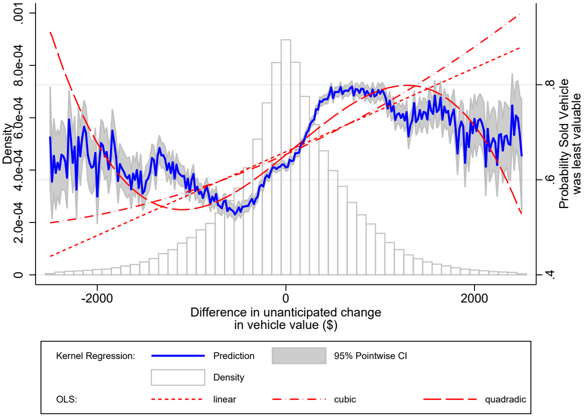
- Candidate 3: Deviations from expected price difference (“DfT”)
  - Let $\mathbf{E}[Dep_{it}^{j}]$ be the expected depreciation of car $j \in \{k, d\}$
  - $\Delta\Delta V_{it}^{kd} = (P_{it}^{k} - \mathbf{E}[Dep_{it}^{k}] \cdot P_{i,t-1}^{k}) - (P_{it}^{d} - \mathbf{E}[Dep_{it}^{d}] \cdot P_{i,t-1}^{d})$
  - Trend Construction Visualize

IV1 Reduced Form (Probability of Drop): DfT

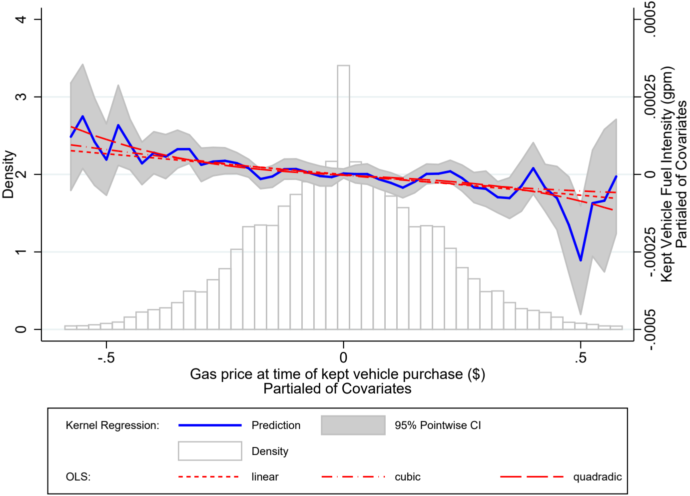
Figure: Prob(sold car least valuable): Price deviation from trend IV



Price Difference Price DiD

IV2 Reduced Form (f_{it}^{k}): $P_{it}^{gas\_k}$

Figure: Gas Price at Kept Purchase on Kept GPM



Overidentification

5 endogenous variables:

$$\mathbf{Z}_{it} = \left[\begin{array}{cccccc} \mathbb{1}_{it}^{k>d} & \mathbb{1}_{it}^{k>d} \times f_{it}^{k} & \mathbb{1}_{it}^{k>d} \times p_{it}^{gas} \times f_{it}^{k} & \mathbb{1}_{it}^{d\geq k} \times f_{it}^{k} & \mathbb{1}_{it}^{d\geq k} \times p_{it}^{gas} \times f_{it}^{k} \end{array} \right]'$$

Many candidate IVs:

$$\mathbf{V}_{it}^{kd} = \left[\begin{array}{ccccc} (\Delta\Delta V_{it}^{kd}) & (\Delta\Delta V_{it}^{kd})^2 & (\Delta\Delta V_{it}^{kd})^3 & p_{it_k}^{gas_k} & p_{it_d}^{gas_d} \end{array} \right]'$$

...and...

$$\mathbf{V}_{it}^{kd} \times p_{it}^{gas}$$

...and other interactions of $\mathbf{V}_{it}^{kd}$

Overidentification

Avoid proliferation of IVs following Wooldridge (2002)

- Estimate the first-stage relationships for the uninteracted endogenous variables $\mathbb{1}^{k>d}$ and f_{it}^k.
  - For example:

$$f_{it}^k = \Gamma_0 + \Gamma_V V_{it}^{kd} + \Theta X_{it} + \Xi_{it}^w$$

- Retrieve projections $\widehat{\mathbb{1}^{k>d}}$ and $\widehat{f_{it}^k}$
- Augment V_{it}^{kd} with four new IVs:

$$\widehat{\mathbb{1}^{k>d} \times f_{it}^k} = \widehat{\mathbb{1}^{k>d}} \times \widehat{f_{it}^k} \qquad \mathbb{1}^{k>d} \widehat{\times f_{it}^k} \times p_{it}^{gas} = \widehat{\mathbb{1}^{k>d}} \times \widehat{f_{it}^k} \times p_{it}^{gas}$$

$$\widehat{\mathbb{1}^{d\geq k} \times f_{it}^k} = (1 - \widehat{\mathbb{1}^{k>d}}) \times \widehat{f_{it}^k} \qquad \mathbb{1}^{d\geq k} \widehat{\times f_{it}^k} \times p_{it}^{gas} = (1 - \widehat{\mathbb{1}^{k>d}}) \times \widehat{f_{it}^k} \times p_{it}^{gas}$$

Results that follow

- Multi-car HH sample comparison
- Main regression results
  - OLS, IV, HHFE, HHFEIV
  - Marginal Effects
- Attribute regressions
  - LHS: footprint, engine displacement, weight
- Counterfactual
  - Is the portfolio effect relevant for CAFE standards?

2-Car "Replacement" Households Sample

	2x2 Households HHFEIV Sample	1x2 Households HHFEIV Sample	3x3 Households HHFEIV Sample
Kept Vehicle GPM	0.0519	0.0513	0.0534
	(0.0108)	(0.0110)	(0.0113)
Bought Vehicle GPM	0.0516	0.0509	0.0517
	(0.0107)	(0.0111)	(0.0110)
Dropped Vehicle GPM	0.0504		0.0505
	(0.0104)		(0.0107)
Gasoline Price at Bought Purchase (US$)	2.165	2.538	2.161
	(0.621)	(0.789)	(0.596)
Gas Price at Kept Vehicle Purchase (US$)	1.917	2.180	1.886
	(0.416)	(0.583)	(0.396)
(Kept - Sold) Value DfT (US$)	6.260		-2.926
	(845.771)		(688.030)
Kept Vehicle Age (yr)	7.472	7.407	10.453
	(4.955)	(4.870)	(4.909)
Dropped Vehicle Age (yr)	9.753		10.013
	(4.929)		(5.013)
Kept vehicle value (US$)	10,404	10,366	6,564
	(8,457)	(8,536)	(6,173)
Bought Vehicle Value (US$)	11,905	9,870	11,460
	(9,146)	(8,391)	(9,133)
Dropped Vehicle Value (US$)	7,325		7,107
	(7,136)		(7,108)
N Transactions	818,197	2,155,728	163,517
N Households	648,058	2,038,458	128,520

Base Results: Continuous (New)

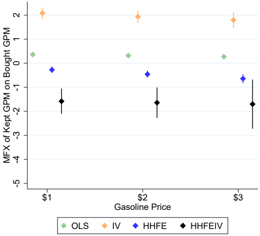
	OLS (1) No IV/FE	IV (2) No FE	HHFE (3) No IV	HHFEIV (4) FE+IV
New				
$\mathbb{1}^{d \geq k} \times GPM^k$	0.4170	-0.0376	0.0881	-0.6440
	(0.0097)***	(0.0788)	(0.0390)**	(0.2879)**
$\mathbb{1}^{k>d} \times GPM^k$	0.2205	-0.0691	-0.0821	-0.5686
	(0.0076)***	(0.0489)	(0.0311)***	(0.1775)***
$\mathbb{1}^{d \geq k} \times GPM^k \times p^{gas}$	-0.0325	-0.0933	-0.2562	-0.3121
	(0.0041)***	(0.0232)***	(0.0154)***	(0.0526)***
$\mathbb{1}^{k>d} \times GPM^k \times p^{gas}$	-0.0110	-0.0422	-0.1905	-0.1907
	(0.0032)***	(0.0120)***	(0.0126)***	(0.0444)***
p^{gas}	0.0004	0.0027	0.0117	0.0131
	(0.0002)**	(0.0009)***	(0.0008)***	(0.0025)***
N Non-singleton	384,692	384,692	140,209	140,209
Cragg-Donald Stat		58.544		159.57
Instrumental Vars	N/A	GP+DfT+I	N/A	GP+DfT+I
Fixed Effects	None	None	HH	HH

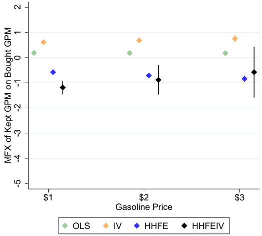
Base Results: Used

Marginal Effects: GPM^k on GPM^d

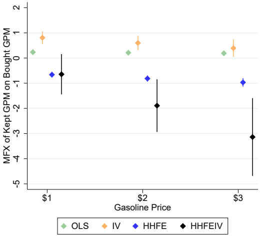
$GPM^k < GPM^d$ ("More") | $GPM^k > GPM^d$ ("Less")

New





Used



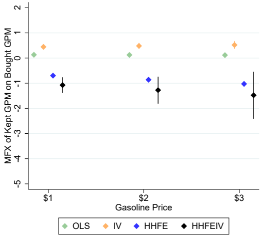


Table: New Table: Used

Rationale for Attribute Regressions

- Fuel intensity is correlated with many desirable vehicle attributes
  - Power, safety, comfort, etc.
- Recall attribute-based standards
  - CAFE (US) is linked to vehicle footprint
  - New European Driving Cycle is linked to vehicle weight

If kept-car fuel intensity affects bought car footprint, it will have direct impacts on fuel savings under CAFE.

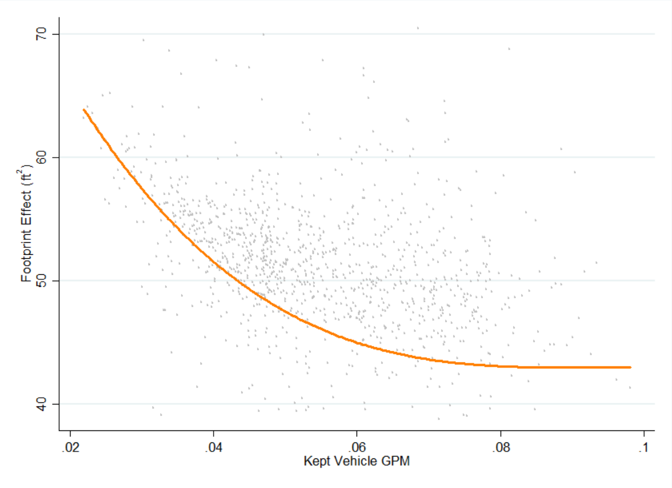
Attribute Marginal Effects: GPM^k (New)

	Footprint (1) $f^d \geq f^k$	Footprint (2) $f^k > f^d$	Curb wt. (3) $f^d \geq f^k$	Curb wt. (4) $f^k > f^d$	Displacement (5) $f^d \geq f^k$	Displacement (6) $f^k > f^d$
New						
$p^{gas} = \$2.00$	-972.96	-841.94	-12.337	-17.824	-194.09	-139.92
	(235.81)***	(183.91)***	(7.621)	(5.002)***	(89.82)**	(75.63)*
$p^{gas} = \$3.00$	-1,148.4	-938.0	-22.850	-25.292	-215.46	-150.08
	(240.2)***	(198.5)***	(7.371)***	(5.276)***	(91.38)**	(76.16)**
$p^{gas} = \$4.00$	-1,323.8	-1,034.1	-33.364	-32.760	-236.83	-160.25
	(251.4)***	(217.6)***	(7.350)***	(5.802)***	(93.07)**	(76.83)**

Attributes: Used

Attribute Up-Sizing: In Perspective (1)

Figure: Portfolio effect: GPM^k on bought car footprint



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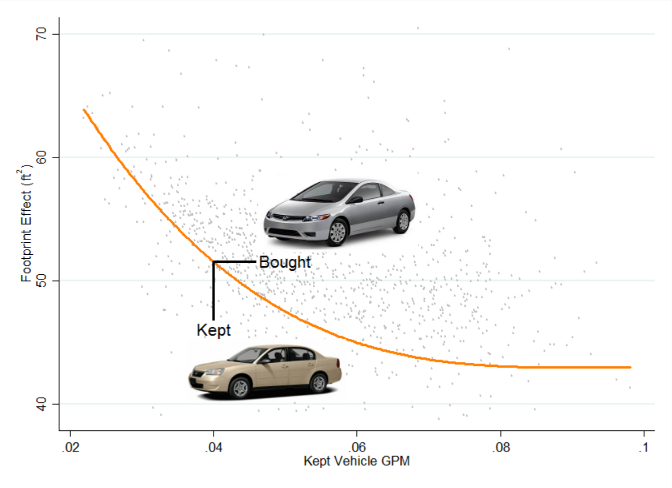

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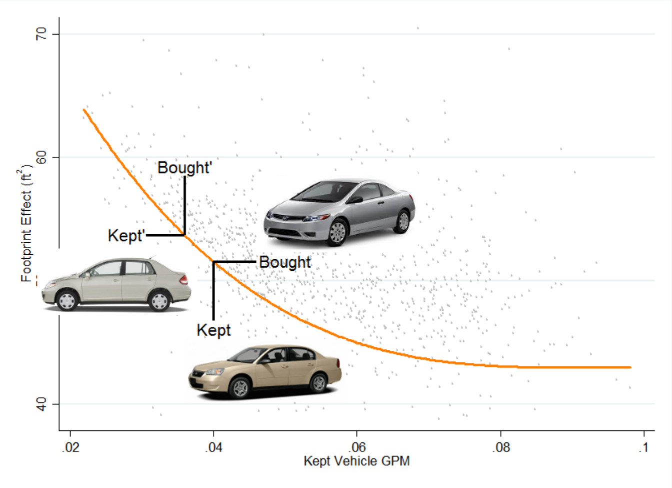

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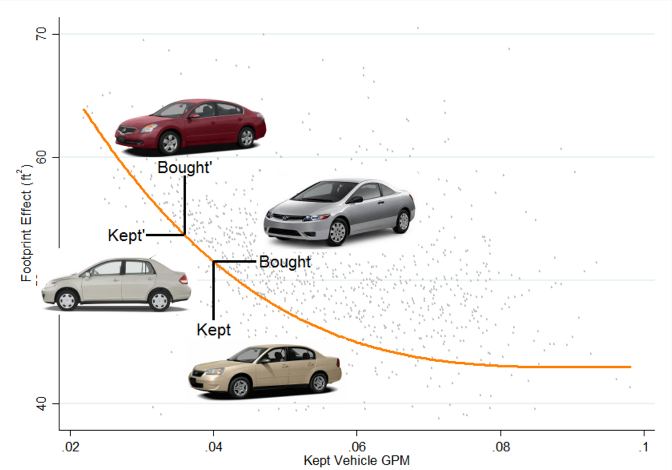

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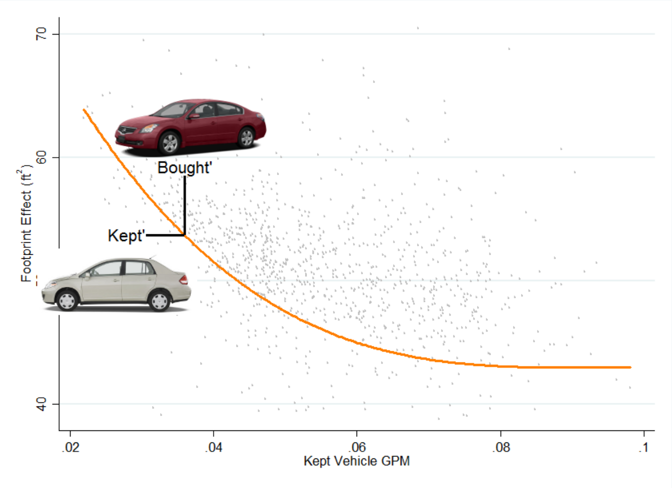
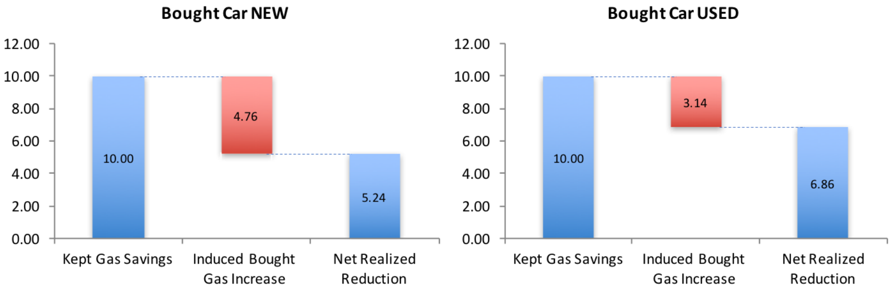


Counterfactuals

Consider effect of fuel economy standards implemented several years ago

1. Decrease kept-car GPM
2. Allow bought-car GPM to adjust according to MFX
3. Hold fixed VMT
   - No rebound
   - No within-HH VMT substitution
4. Calculate gasoline usage for both cars (GPM*VMT)
5. Retrieve net change in gasoline usage

Gasoline Savings Erosion from Portfolio Effect



Table

Conclusions

- New identification strategy for retrieving household portfolio preferences
- Strong attribute substitution across cars in household portfolio
- Applies strong force counterveiling fuel economy standards
  - Of particular concern with attribute-basing

Next Steps

We will extend and deepen the analysis in several ways

- Extend and refine policy counterfactual
  - Welfare effects
- Examine portfolio effects on VMT (medium-run)

Thank You!

Comments and questions appreciated:

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Appendix

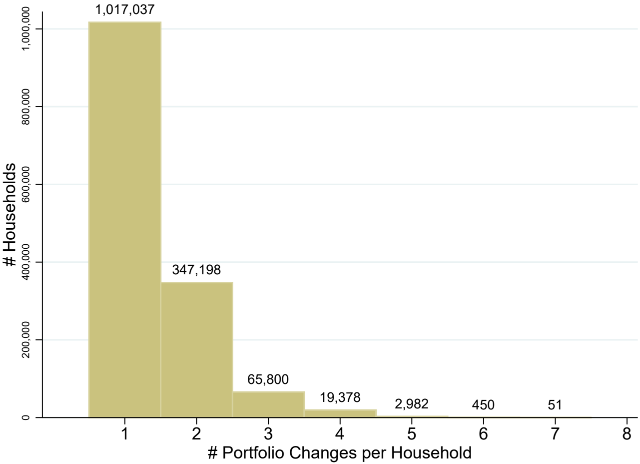
The "Portfolio Effect"

To what extent does changing the attributes of one car that a household owns affect the choice of the second (or third) car?

Empirical sample

Restrict focus to 2-car households

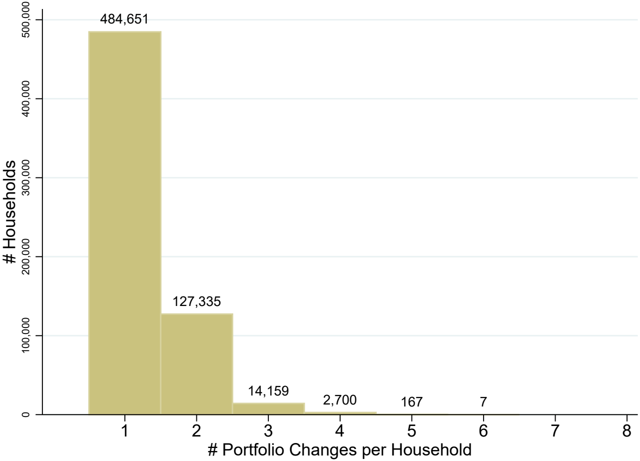
Figure: Number of Transactions: OLS Sample



Empirical sample

Restrict focus to 2-car households

Figure: Number of Transactions: IV Sample



Computing Unanticipated Value Change (DfT)

1. Compute 1-year deprecation rates by Vehicle Make, Class, and age
   1. e.g., Consider a 1999 Toyota Camry in 2002
2. Average the deprecation rates of vehicle in the same category over the previous 5 years
   1. e.g., 1997 Toyota cars in 2001, 1996 Toyota cars in 2000, etc.
   2. Considered other horizons for averaging (1 year, 3 years) but 5 was the best predictor of future depreciation rates
3. Apply the average depreciation rate to NADA vehicle value from the previous year to compute the expected value in the current year
4. Subtract expected value in the current year from the current year NADA value to compute the deviation from trend.

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Visualize DfT Instrument

Figure: DfT instrument example

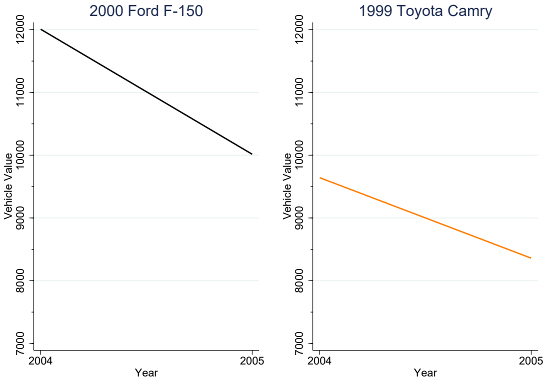

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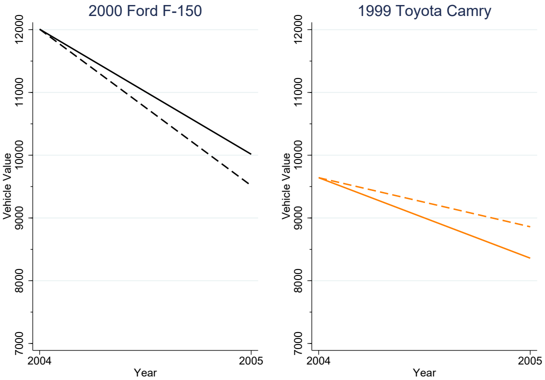
Figure: DfT instrument example



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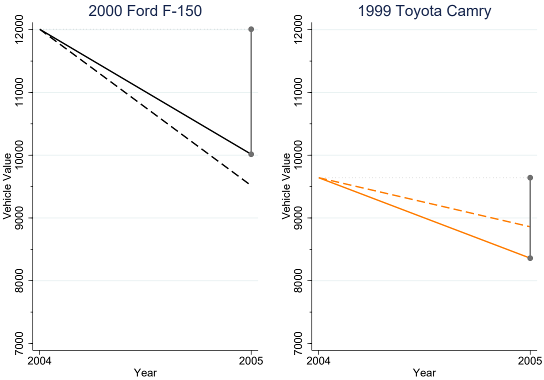

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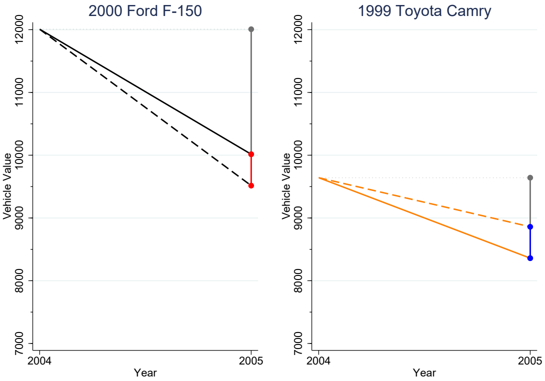

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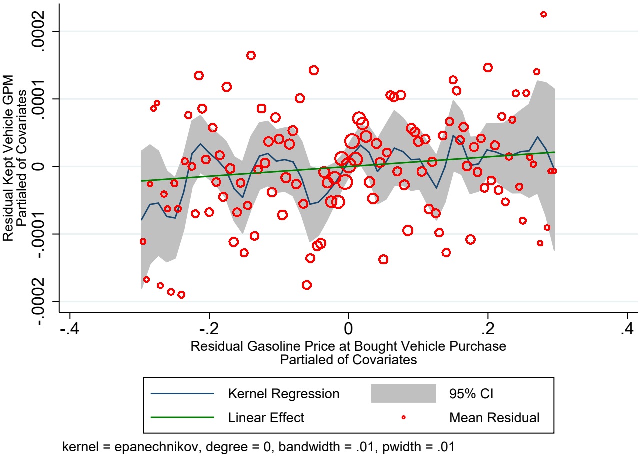
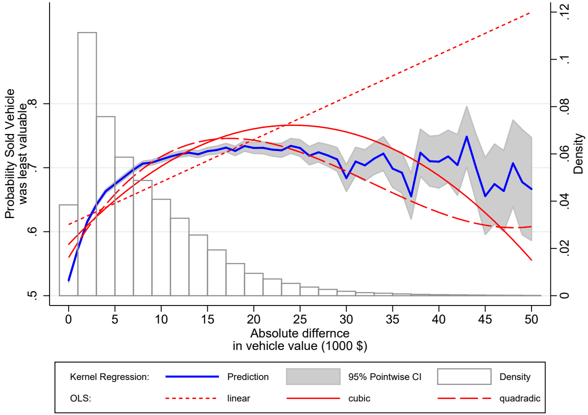
IV2 Reduced Form ($p^{gas}_{it_k}$): New Vehicle Purchases

Figure: Partialed f^b_{it} vs Partialed $p^{gas}_{it_k}$



IV1 Reduced Form (Probability of Drop): Diff

Table: Prob(sold car least valuable): Price deviation from trend IV



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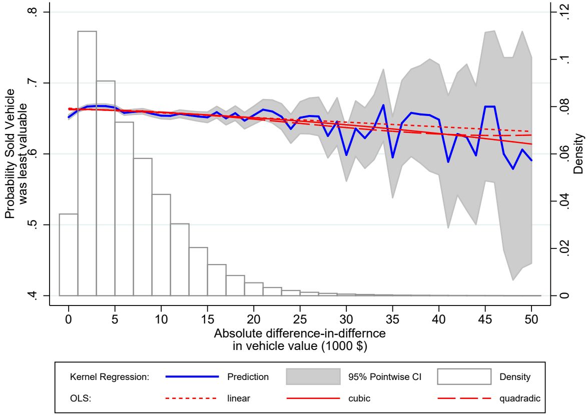

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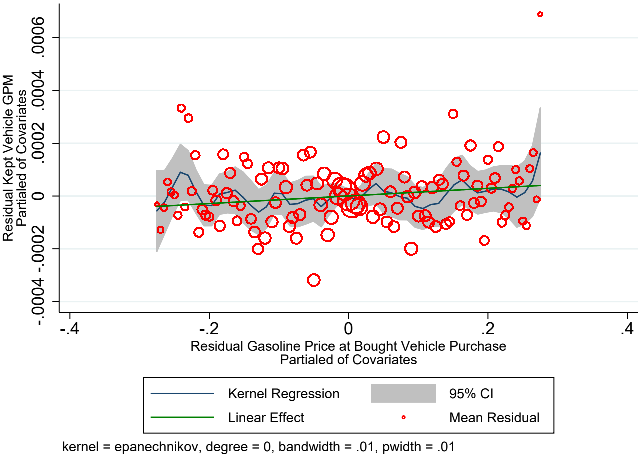
IV2 Reduced Form ($p^{gas}_{it_k}$): Used Vehicle Purchases

Figure: Partialed f^b_{it} vs Partialed $p^{gas}_{it_k}$



Base Results: Continuous (Used)

	OLS (1) No IV/FE	IV (2) No FE	HHFE (3) No IV	HHFEIV (4) FE+IV
Used				
$\mathbb{1}^{d \geq k} \times GPM^k$	0.2561	0.3495	-0.0473	0.1660
	(0.0104)***	(0.0726)***	(0.0407)	(0.2342)
$\mathbb{1}^{k>d} \times GPM^k$	0.1584	0.1709	-0.1852	-0.1456
	(0.0079)***	(0.0499)***	(0.0327)***	(0.1402)
$\mathbb{1}^{d \geq k} \times GPM^k \times p^{gas}$	-0.0176	0.0153	-0.2582	-0.4104
	(0.0043)***	(0.0327)	(0.0162)***	(0.0327)***
$\mathbb{1}^{k>d} \times GPM^k \times p^{gas}$	-0.0101	0.0068	-0.1907	-0.2612
	(0.0034)***	(0.0161)	(0.0130)***	(0.0268)***
p^{gas}	0.0005	-0.0008	0.0112	0.0169
	(0.0002)**	(0.0012)	(0.0008)***	(0.0015)***
N Non-singleton	395,754	395,754	140,256	140,256
Cragg-Donald Stat		61.194		140.38
Instrumental Vars	N/A	GP+DfT+I	N/A	GP+DfT+I
Fixed Effects	None	None	HH	HH

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Marginal Effect of f^k: Continuous (New)

	OLS (1) $f^d \geq f^k$	OLS (2) $f^k > f^d$	IV (3) $f^d \geq f^k$	IV (4) $f^k > f^d$	HHFE (5) $f^d \geq f^k$	HHFE (6) $f^k > f^d$	HHFEIV (7) $f^d \geq f^k$	HHFEIV (8) $f^k > f^d$
New								
$p^{gas} = \$2.00$	0.3519	0.1986	-0.2241	-0.1534	-0.4242	-0.4630	-1.2681	-0.9500
	(0.0046)***	(0.0035)***	(0.0985)**	(0.0592)***	(0.0218)***	(0.0180)***	(0.2731)***	(0.1744)***
$p^{gas} = \$3.00$	0.3194	0.1876	-0.3174	-0.1956	-0.6804	-0.6535	-1.5802	-1.1407
	(0.0059)***	(0.0046)***	(0.1143)***	(0.0671)***	(0.0259)***	(0.0219)***	(0.2807)***	(0.1891)***
$p^{gas} = \$4.00$	0.2869	0.1766	-0.4106	-0.2377	-0.9366	-0.8440	-1.8923	-1.3314
	(0.0090)***	(0.0071)***	(0.1322)***	(0.0760)***	(0.0366)***	(0.0309)***	(0.2975)***	(0.2123)***

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Marginal Effect of f^k: Continuous (Used)

	OLS (1) $f^d \geq f^k$	OLS (2) $f^k > f^d$	IV (3) $f^d \geq f^k$	IV (4) $f^k > f^d$	HHFE (5) $f^d \geq f^k$	HHFE (6) $f^k > f^d$	HHFEIV (7) $f^d \geq f^k$	HHFEIV (8) $f^k > f^d$
Used								
$p^{gas} = \$2.00$	0.2208	0.1382	0.3802	0.1845	-0.5637	-0.5665	-0.6549	-0.6679
	(0.0049)***	(0.0036)***	(0.0716)***	(0.0566)***	(0.0211)***	(0.0172)***	(0.2177)***	(0.1269)***
$p^{gas} = \$3.00$	0.2032	0.1281	0.3955	0.1913	-0.8219	-0.7572	-1.0653	-0.9291
	(0.0061)***	(0.0047)***	(0.0909)***	(0.0659)***	(0.0250)***	(0.0204)***	(0.2165)***	(0.1283)***
$p^{gas} = \$4.00$	0.1856	0.1180	0.4108	0.1981	-1.0801	-0.9479	-1.4757	-1.1903
	(0.0093)***	(0.0073)***	(0.1163)***	(0.0774)**	(0.0364)***	(0.0297)***	(0.2201)***	(0.1352)***

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Attribute Marginal Effects: GPM^k (Used)

	Footprint (1) $f^d \geq f^k$	Footprint (2) $f^k > f^d$	Curb wt. (3) $f^d \geq f^k$	Curb wt. (4) $f^k > f^d$	Displacement (5) $f^d \geq f^k$	Displacement (6) $f^k > f^d$
Used						
$p^{gas} = \$2.00$	-269.00	-125.38	-19.972	-12.467	-135.64	-117.21
	(188.86)	(177.48)	(8.536)**	(7.909)	(141.16)	(128.78)
$p^{gas} = \$3.00$	-416.15	-208.64	-29.128	-18.116	-175.92	-142.10
	(196.31)**	(194.25)	(9.198)***	(8.907)**	(148.13)	(132.88)
$p^{gas} = \$4.00$	-563.29	-291.89	-38.284	-23.765	-216.20	-167.00
	(209.72)***	(213.57)	(10.127)***	(10.023)**	(155.17)	(137.03)

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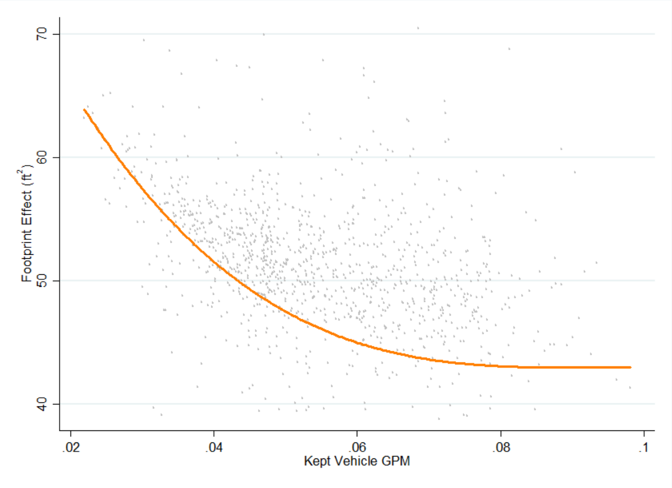
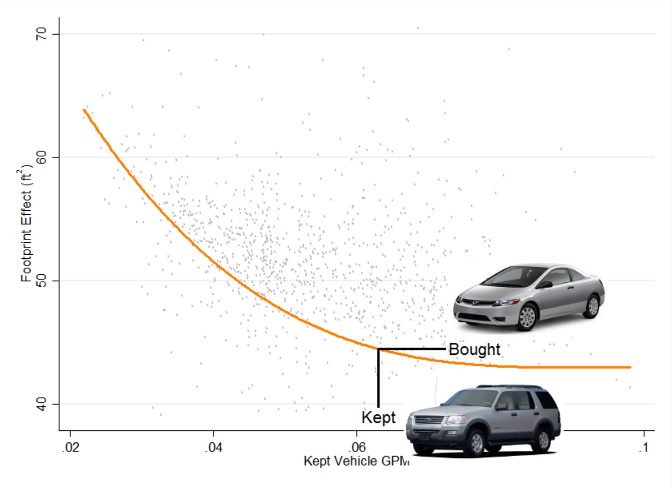
Attribute Up-Sizing: In Perspective (2)

Figure: Portfolio effect on bought car footprint



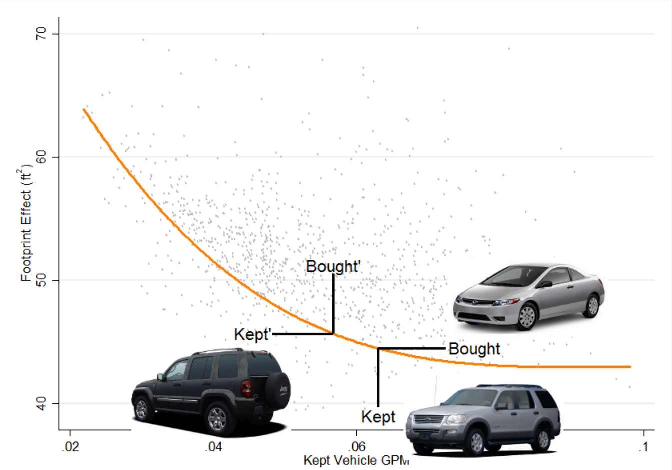
Attribute Up-Sizing: In Perspective (2)

Figure: Portfolio effect on bought car footprint



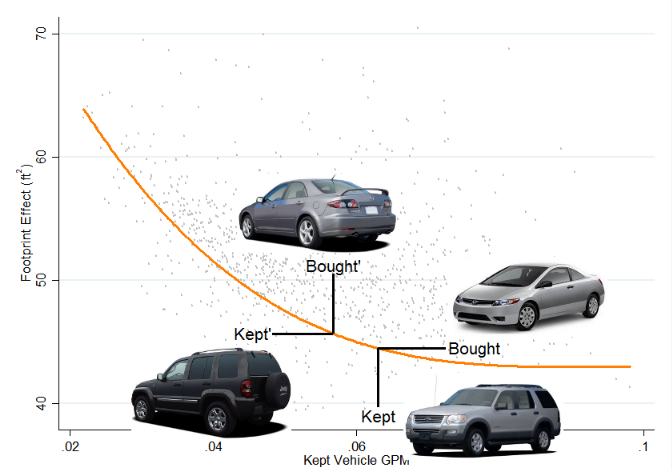
Attribute Up-Sizing: In Perspective (2)

Figure: Portfolio effect on bought car footprint



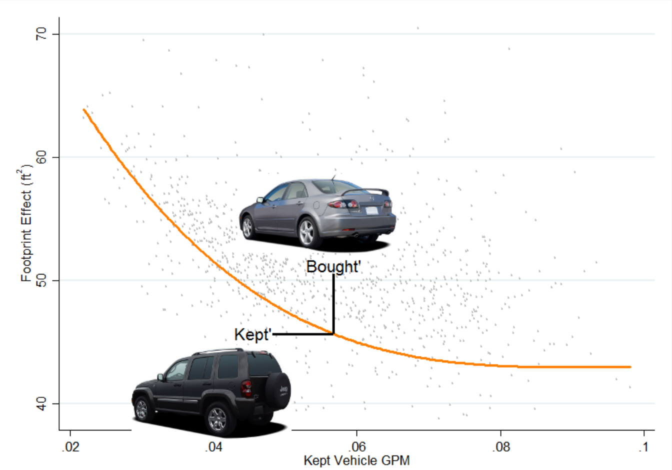
Attribute Up-Sizing: In Perspective (2)

Figure: Portfolio effect on bought car footprint



Attribute Up-Sizing: In Perspective (2)

Figure: Portfolio effect on bought car footprint



Gasoline Consumption Counterfactuals

Table: Households Purchasing New Vehicles

Vehicle	Observed Gasoline Consumption (gal/yr)	Change in Gasoline Consumption: New Vehicles
Kept	537.64	-10.00
Bought	555.34	4.76
Total	1,092.98	-5.24

Table: Households Purchasing Used Vehicles

Vehicle	Observed Gasoline Consumption (gal/yr)	Change in Gasoline Consumption: Used Vehicles
Kept	569.12	-10.00
Bought	537.29	3.14
Total	1,106.41	-6.86

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