Gas Prices, Fuel Efficiency and Endogenous Product Selection in the U.S. Automobile Industry

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Goals

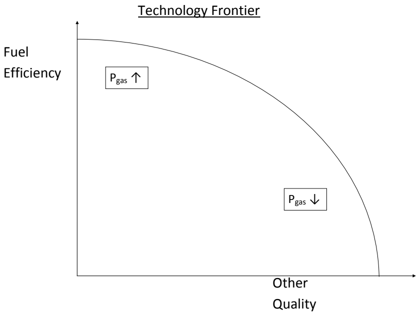
1. Model auto manufacturers' choices of fuel efficiency (*mpg*)
2. Use model to predict market equilibrium in counterfactual scenarios
    - Gas prices increases
    - Gasoline taxes

Why?

1. Understand determination of product characteristics
   - (Non-price) Chars often of interest (variety, quality, efficiency...)
   - Limited endogenous modeling (theoretical v empirical)
2. Auto Industry & *mpg*
   - Industry: 3% GDP, 20% energy use, 20% CO_2 emissions
   - *mpg*: indicator of environmental impact, CAFE target
3. Relation to Literatures on each

Overview

- BLP (1995) with characteristic-setting game beforehand



- Stochastic $p_{gas} \Rightarrow$ consumer prefs $\Rightarrow$ firms' optima
- No vehicle introduction, adjustment on existing models

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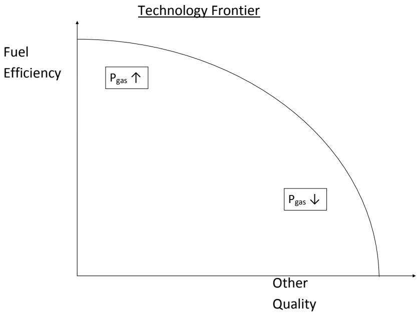

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Preview of Results

1. Modeling
    1. Model product selection - find exogenous shifters
    2. Less restrictive ID assumptions - allow $corr(mpg, \xi)$
    3. Realistic utility estimates - unobservable quality in *mpg*
2. Counterfactuals - predict *mpg* equilibrium at any (after-tax) p_{gas}
    1. Summer 2008 ($3.43): reasonable fit?
    2. “CAFE-equivalent" gas price: $4.55

Model: Demand

$$u_{ijt} = \alpha p_j + \beta_d dpm_j + \beta_m ln(mpg_j) + \xi_j + BX_{jt} + \tilde{\epsilon}_{ij} \quad (1)$$

econon *qual*

- $dpm_j = \frac{pgas_t}{mpg_j}$
- Why $ln(mpg)$ as proxy for *qual*?
  - Condit. on *dpm*, *mpg* is best proxy (and *ln* appropriate shape)
- Why fewer preference chars. than BLP?
  - I assume nesting structure captures them
  - Because there aren't exogenous shifters
- ξ_j used in estimation moments, but less restrictively (corr w/ ξ)

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Model: Share Function

Rewriting utility:

$$u_{ijt} = \delta_j + \tilde{\epsilon}_{ijt} \tag{2}$$

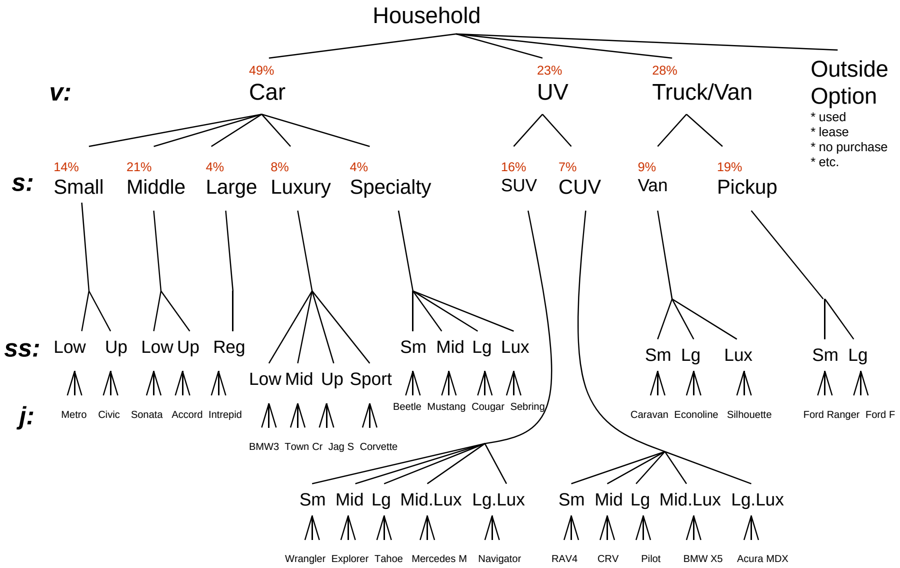
$$\tag{3}$$

Share function:

$$s_j = \frac{e^{\frac{\delta_j}{1-\sigma_{ss}}}}{D_{ss}} * \frac{D_{ss}^{\frac{1-\sigma_{ss}}{1-\sigma_s}}}{D_s} * \frac{D_s^{\frac{1-\sigma_s}{1-\sigma_t}}}{D_t} * \frac{D_t^{1-\sigma_t}}{D_a} \tag{4}$$

$$ln\frac{s_j}{s_o} = \sigma_{ss} ln\frac{s_j}{s_{ss}} + \sigma_s ln\frac{s_{ss}}{s_s} + \sigma_v ln\frac{s_s}{s_v} + \delta_j \tag{5}$$

Nesting Structure



Model: Supply

Timing of Events

Time t-1		Time t		
ξ_t, ω_t	mpg_t	$P_{gas,t}$	p_t	q_t
Shocks	Characteristic	Shock	Characteristic	Purchases
Revealed by nature	Chosen by firms	Revealed by nature	Chosen by firms	Chosen by csrs

Model: FOC's

Firm Maximization Problem

$$\max_{\mathbf{mpg_f}} E_{p_{gas}} \left[\max_{\mathbf{p_f}} \Pi_f \right] \quad (6)$$

First Order Conditions

$$s_j + \sum_{r \in \Im_f} \left[(p_r - mc_r) \frac{\partial s_r}{\partial p_j} + s_r \lambda \{bind\} \frac{\partial \overline{mpg_f}}{\partial p_j} \right] = 0$$

$$E_{p_{gas}} \left[\sum_{r \in \Im_f} \left[s_r \left(\frac{\partial p_r}{\partial mpg_j} - \frac{\partial mc_r}{\partial mpg_j} \right) + (p_r - mc_r) \frac{\partial s_r}{\partial mpg_j} + s_r \lambda \{bind\} \frac{\partial \overline{mpg_f}}{\partial mpg_j} \right] \right] = 0$$

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Model: Supply - Marginal Cost

$$ln(mc_j) = \gamma_1 + \gamma_2 ln(mpg) + \Gamma X_{jt} + \omega_j \quad (7)$$

- interpretation of parameters
- ω_j used in estimation moments, but less restrictively

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Estimation - GMM

$$min_{\theta} \begin{pmatrix} \xi_t(\theta) * H_{t-1} \\ \omega_t(\theta) * H_{t-1} \\ R_{jt}(\theta) * I_{t-1}(\theta) \end{pmatrix} W_n \begin{pmatrix} \xi_t(\theta) * H_{t-1} \\ \omega_t(\theta) * H_{t-1} \\ R_{jt}(\theta) * I_{t-1}(\theta) \end{pmatrix}' \qquad (8)$$

- 1 and 2 - literature adds $E[\xi_{jt} * mpg_{jt}] = 0$
- 3 means no systematic/predictable mis-optimization by firms
  - Hansen Singleton 1982
  - Reduces computational burden
  - Allows agnosticism on expectations of p_{gas}
- No additional assumptions, just implications of the timing

Estimation Moments

Timing of Events

Time t-1				Time t			
H_{t-1}	$\boldsymbol{\xi_t, \omega_t}$	**mpg_t**	I_{t-1}	$P_{gas,t}$	**p_t**	**q_t**	**R_t**
Information set	Shocks	Characteristic	Information set	Shock	Characteristic	Purchases	Ex post regret in **mpg_t** choice
Known by all	Revealed by nature	Chosen by firms	Known by all	Revealed by nature	Chosen by firms	Chosen by csrs	Revealed by nature
Includes: * time t models' sub-segments * time t models' manufacturers * $p_{gas,t-1}$			Includes: * time t models' sub-segments * time t models' manufacturers * $p_{gas,t-1}$ * **ξ_t, ω_t** * **mpg_t**				Due to $p_{gas,t}$

Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Year	1992.5	11.1	1971	2007
Mpg	20.7	5.8	9.13	61
Dpm	$0.10	$0.04	$0.03	$0.24
Price	$30,059	$21,195	$7,038	$115,000
q	75,566	95,043	123	890,790
Price gas	$2.02	$0.48	$1.31	$3.15
Price gas change	$0.05	$0.24	-$0.56	$0.68
GDP Growth	3.1%	1.7%	-1.9%	7.2%
N Models in Year	150.6	55.9	72	249

N Model-Years	4,820
N Years	32
N Types	3
N Segments	9
N Sub-segments	28

Note: Prices are Real 2007 Dollars

GMM Estimation Results

Demand parameters:

Variable		Coeff	S.E.	T-stat
price ($10k)	α	-0.33	0.02	-18.41
ln mpg	β_m	-0.75	0.17	-4.51
dpm Car small	β_d	-4.70	0.66	-7.13
dpm Car middle	β_d	-5.55	0.55	-10.01
dpm Car large	β_d	-4.68	0.65	-7.16
dpm Car luxury	β_d	-2.13	0.43	-4.98
dpm Car specialty	β_d	-4.02	0.44	-9.17
dpm CUV	β_d	-9.07	2.95	-3.08
dpm SUV	β_d	-8.10	1.13	-7.20
dpm Truck	β_d	-4.17	0.70	-5.98
dpm Van	β_d	-3.65	0.70	-5.20
gdp gr	β	2.06	0.36	5.79
gdp per cap	β	0.02	0.01	1.45
cuv x year	β	0.08	0.03	2.50
suv x year	β	0.11	0.01	8.11
autonews datasource	β	0.34	0.04	8.33
asian	β	-0.06	0.01	-4.52
euro	β	0.14	0.03	5.30
partial year of sales	β	-0.57	0.02	-27.06
$\ln(s_{j\|ss})$ †	σ_{ss}	0.78	0.00	388
$\ln(s_{ss\|s})$ †	σ_s	0.92	0.00	1081
$\ln(s_{s\|t})$ †	σ_v	0.83	0.00	360
Subsegment_dums ‡ (range -4.07 to 0.56)	β	1.28	0.23	4.76

Cost parameters:

Variable		Coeff	S.E.	T-stat
ln mpg	γ	-0.03	0.11	-0.32
year	γ	0.03	0.00	14.72
autonews	γ	0.32	0.05	6.14
asian	γ	0.16	0.02	6.78
euro	γ	0.60	0.03	21.96
Subsegment_dums ‡ (range 9.02 to 10.74)	γ	9.86	0.21	47.87
CAFÉ	λ	$ 347	$ 3.4	102

Estimation Results

Willingness to Pay for 20% MPG increase

By Segment and By Gas Price

Segment	Small	Middle	Large	Luxury	Specialty	CUV	SUV	Truck	Van
Mean MPG *	31.2	28.3	20.2	20.3	22.0	22.8	16.2	17.2	18.1
20% of Mean MPG	6.2	5.7	4.0	4.1	4.4	4.6	3.2	3.4	3.6
p_gas									
$4.55	$ 1,554	$ 3,457	$ 4,030	$ 556	$ 2,380	$ 7,571	$ 9,964	$ 4,440	$ 3,413
$3.43	$ 720	$ 2,154	$ 2,586	$ (33)	$ 1,342	$ 5,256	$ 7,059	$ 2,895	$ 2,121
$1.50	$ (718)	$ (91)	$ 98	$ (1,047)	$ (446)	$ 1,265	$ 2,054	$ 233	$ (105)

* 2007 Sales-Weighted, Segment-Average MPG

Negative entries are due to the quality reductions required to improve MPG (within a sub-segment).

Estimation Results

1. Parameters with sensible signs and magnitudes
2. CUV/SUV consumers most sensitive to *mpg*
3. CAFE - $347 per American car since 1977
4. Cost parameter insignificant - as expected

Counterfactuals

- Model can calculate market equilibrium at any p_{gas} (after-tax)
  1. Summer 2008 gas prices ($3.43)
  2. “CAFE-equivalent" after-tax gas price ($4.55)

Counterfactuals

Table: Actual and Predicted Sales Declines, Summer 2008

Aggregation Level	Actual	Model Prediction
Cars	-3%	-9%
Utility Vehicles	-19%	-23%
Trucks	-16%	-13%
Total	**-13%**	**-14%**

Counterfactuals

Model Predictions for $3.43 gas

Vehicle Classification			Quantity †			MPG Offered †			MPG Purchased †		
Type	Segment	# Models	2007	2008	2009	2007	2008 ‡	2009	2007	2008	2009
Car		140	7,567	6,861	7,266	22.6	22.6	19.0	26.8	27.6	19.3
				-9%	-4%		0%	-16%		3%	-28%
	Small	29	2,312	2,357	2,350	28.3	28.3	21.1	31.2	31.8	21.0
	Middle	27	2,893	2,136	1,714	24.4	24.4	29.8	28.3	30.4	30.1
	Large	14	674	479	320	19.9	19.9	24.1	20.2	20.3	23.8
	Luxury	49	1,192	1,440	2,551	19.6	19.6	10.3	20.3	20.4	10.0
	Specialty	21	496	451	332	21.4	21.4	18.9	22.0	22.5	18.5
UV		93	4,644	3,577	4,716	18.5	18.5	41.4	19.9	21.9	41.0
				-23%	2%		0%	124%		10%	106%
	CUV	54	2,636	2,320	2,058	20.6	20.6	43.2	22.8	24.7	43.4
	SUV	39	2,008	1,257	2,658	15.5	15.5	39.0	16.2	16.7	39.2
Truck/Van		37	3,673	3,181	3,129	18.0	18.0	20.6	17.4	17.8	21.0
				-13%	-15%		0%	14%		2%	20%
	Pickup	21	2,730	2,264	2,290	18.4	18.4	21.7	17.2	17.6	21.6
	Van	16	943	916	839	17.6	17.6	19.1	18.1	18.4	19.2
All Vehicles		**270**	**15,883**	**13,619**	**15,110**	**20.6**	**20.6**	**26.9**	**22.6**	**23.8**	**26.4**
				-14%	**-5%**		**0%**	**31%**		**5%**	**17%**

† All percentages (shaded) are percentage changes from 2007 levels
‡ 2008 Fuel Efficiency Offerings are fixed at 2007 levels for comparability

Quantity = Sales (1000s)
MPG Offered = Raw-average MPG across models
MPG Purchased = Sales-weighted MPG

2007 - actual
2008 - predicted (before firms adjust characteristics - only consumers respond)
2009 - predicted (after firms adjustt characteristics)

Counterfactuals

Model Predictions for $4.55 gas

Vehicle Classification			Quantity †			MPG Offered †			MPG Purchased †		
Type	Segment	# Models	2007	2008	2009	2007	2008 ‡	2009	2007	2008	2009
Car		140	7,567	5,878	6,020	22.6	22.6	25.0	26.8	28.6	25.6
				-22%	-20%		0%	11%		7%	-5%
	Small	29	2,312	2,229	1,947	28.3	28.3	27.8	31.2	33.2	27.8
	Middle	27	2,893	1,252	1,420	24.4	24.4	39.6	28.3	35.0	39.9
	Large	14	674	233	265	19.9	19.9	31.6	20.2	20.4	31.6
	Luxury	49	1,192	1,811	2,114	19.6	19.6	13.4	20.3	20.6	13.2
	Specialty	21	496	353	275	21.4	21.4	25.0	22.0	23.6	24.6
UV		93	4,644	2,348	3,907	18.5	18.5	55.1	19.9	25.8	54.4
				-49%	-16%		0%	198%		30%	173%
	CUV	54	2,636	1,873	1,705	20.6	20.6	57.4	22.8	28.0	57.5
	SUV	39	2,008	475	2,202	15.5	15.5	51.8	16.2	17.3	51.9
Truck/Van		37	3,673	2,475	2,593	18.0	18.0	27.3	17.4	18.6	27.8
				-33%	-29%		0%	51%		7%	59%
	Pickup	21	2,730	1,622	1,897	18.4	18.4	28.7	17.2	18.5	28.7
	Van	16	943	853	695	17.6	17.6	25.3	18.1	18.7	25.4
All Vehicles		**270**	**15,883**	**10,701**	**12,520**	**20.6**	**20.6**	**35.7**	**22.6**	**25.7**	**35.0**
				-33%	**-21%**		**0%**	**73%**		**14%**	**55%**

† All percentages (shaded) are percentage changes from 2007 levels
‡ 2008 Fuel Efficiency Offerings are fixed at 2007 levels for comparability

Quantity = Sales (1000s)
MPG Offered = Raw-average MPG across models
MPG Purchased = Sales-weighted MPG

2007 - actual
2008 - predicted (before firms adjust characteristics - only consumers respond)
2009 - predicted (after firms adjustt characteristics)

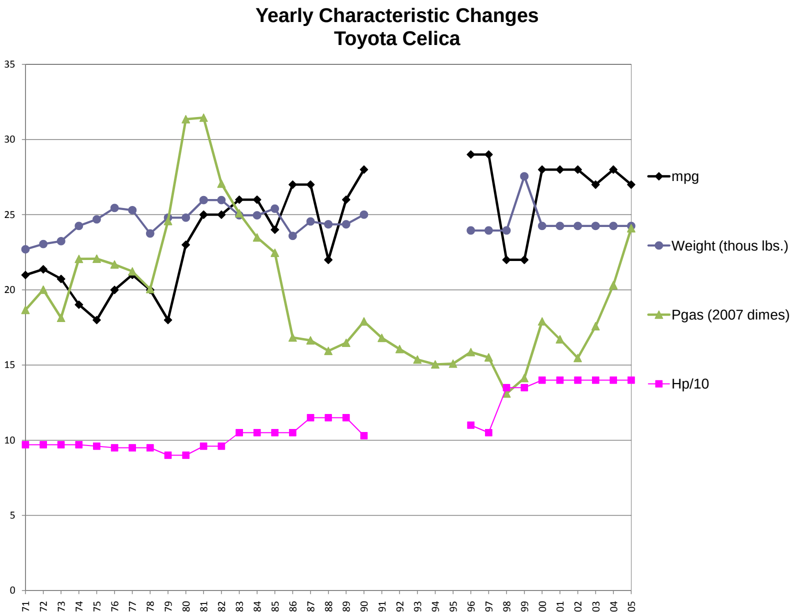
Convergence

Multiple Equilibria do not *appear* to be a problem

- Multiple convergence routines find same eqbm
  - New optima v. FOC derivative
  - Full jumps v. partial
- Ownership, nesting structure may be sufficient to pin down eqbm

Conclusion

1. Model
   - Model product choice
   - Less restrictive demand ID
   - Realistic Fuel Efficiency preference -
     Control for both economic and quality effects of *mpg*
2. Counterfactuals - mapping between p_{gas} and *mpg* equilibrium
   - Summer 2008: comparison to actuals
   - $4.55 would induce 35 *mpg*
3. Other
   - CAFE is costly to domestics ($347 per car)
   - Gas taxes would move *mpg*


Yearly Characteristic Changes
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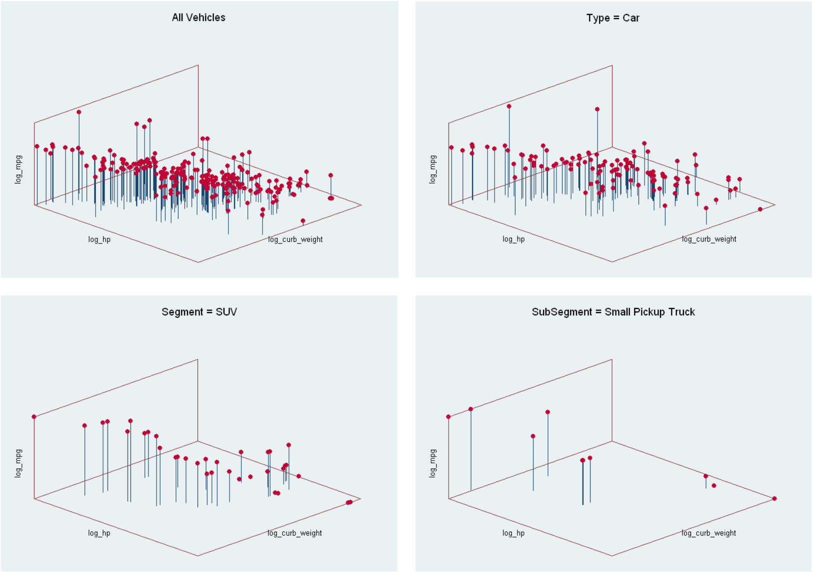
mpg
Weight (thous lbs.)
Pgas (2007 dimes)
Hp/10

Technology Frontier
2007 U.S Vehicles



Technological Tradeoff

OLS Rregression

Dep Var = ln(mpg)	Coef	SE	t
ln(hp)	-0.279	0.008	-37
ln(curb_weight)	-0.596	0.012	-52
year	0.013	0.000	66
const	-16.682	0.397	-42

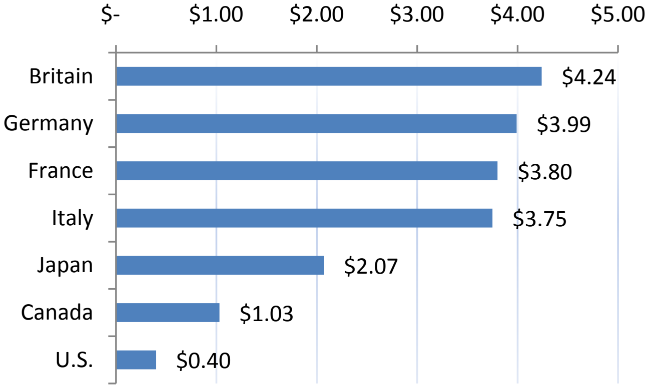
Nobs	4820
R-sq	0.78

R-sq between .4 and .85 for
same regression within subsegment

Gasoline Taxes

Average Gas Taxes Per Gallon

August 2006



U.S. taxes include all State and Federal Taxes

Source: International Energy Agency (IEA), "Energy Prices and Taxes"

As reported in NYT, "Raise the Gasoline Tax?" Oct 2006

Estimation Results

Without Quality Decrease:
Willingness to Pay for 20% MPG increase
By Segment and By Gas Price

Segment	Small	Middle	Large	Luxury	Specialty	CUV	SUV	Truck	Van
Mean MPG *	31.2	28.3	20.2	20.3	22.0	22.8	16.2	17.2	18.1
20% of Mean MPG	6.2	5.7	4.0	4.1	4.4	4.6	3.2	3.4	3.6
p_gas									
$4.55	$ 3,390	$ 5,293	$ 5,866	$ 2,392	$ 4,215	$ 9,407	$ 11,799	$ 6,276	$ 5,249
$3.43	$ 2,556	$ 3,990	$ 4,422	$ 1,803	$ 3,178	$ 7,091	$ 8,895	$ 4,731	$ 3,957
$1.50	$ 1,118	$ 1,745	$ 1,934	$ 789	$ 1,390	$ 3,101	$ 3,890	$ 2,069	$ 1,730

* 2007 Sales-Weighted, Segment-Average MPG

These WTP's:

1) hold quality constant (while improving MPG)
2) therefore do not reflect the economic model
3) are included for comparison to the previous table (which do reflect the economic model)
4) are strictly larger than their counterparts in the previous table
5) are strictly larger than 0

Estimated Correlation of Shocks and Characteristics

	mpg	*p*	ω
ξ	-0.28	0.45	0.25
ω	-0.26	0.61	

- First column new, second column old
- First column smaller (intuition: all quality priced, but not all quality dimensions correlated)
- Cars with high cost (or demand) are low-*mpg*-high-*qual*

Robustness

1. Production lags of 3 and 5 years (rather than 1)
2. Consumers respond to gas prices other ways (besides static price)
3. No sub-segment level in demand
4. Controls on cost/demand