Selection on Anticipated Driving and the Consumer Response to Changing Gasoline Prices

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Research Questions

What is the consumer response to a change in gasoline prices?

1. How much do consumers change their driving when gasoline prices change?
2. How do consumers change their vehicle purchasing behavior when gasoline prices change?

$\rightarrow$ What is the heterogeneity in the responsiveness on each margin?

Why Might We Care?

Economists have long been interested in quantifying the elasticity of gasoline demand. Why?

- Policymakers want to know:
  - Counterfactual effects of a gasoline tax.
    - How much would driving be reduced?
    - Who bears the burden?
    - Implications for local air pollution and congestion?
  - Effects of policies only affecting vehicle choice.
- Firms want to know:
  - How will gasoline demand change with changing gasoline prices?
  - How will vehicle sales change?

Related Literature

Some of the most related literature:

- How driving is affected by gas prices: Hughes, Knittel & Sperling (2008), Small & Van Dender (2007), Knittel & Sandler (2010,2012).
- How vehicle choice is affected by gas prices: Busse, Knittel & Zettelmeyer (2010), Li et al. (2009), Klier & Linn (2010).
- Static modeling of vehicle choice & utilization: Mannering and Winston (1985), Berkowitz et al. (1990), Goldberg (1998), West (2004), Fullerton & Gan (2005), Bento et al. (2009).
- Estimating new vehicle demand system: BLP (1995, 2004), Goldberg (1995).

My Contribution

Jointly estimate how new vehicle purchase and subsequent driving behavior are affected by gasoline prices.

- Using a unique and extremely rich dataset.
- Explicitly model selection into more efficient vehicles.
- Two period model, where consumers base the driving decision on the gasoline price at the time of driving and vehicle choice on information available at time of purchase.
- Explicitly account for how the prices of used vehicles affect new vehicle choice.

My Contribution

I find:

- Medium-run price elasticity of driving for new vehicles around -0.15 and fuel economy around 0.09.
- Selection appears to bias the driving elasticity away from zero, consistent with consumers who know they are going to drive a lot purchasing more efficient vehicles.
- Both a policy leading to $1 increase in gas price and feebate lead to a relatively small welfare loss.
- Estimate of the direct rebound effect from the feebate policy: elasticity of 0.06

Data Sources

- All new vehicle registrations in CA, 2001-2009 (R.L. Polk).
  - VIN, make, model, series, subseries, weight, drivetype, fuel, engine size, cylinders, turbo, buyer type, MSRP, zip code of purchaser, income (sub-sample).
- Smog check data for CA counties with smog check 2003-2010 (CA BAR).
  - VIN, zip code, **odometer reading**, pollutant reading.
- EPA fuel economy ratings.
- Vehicle safety ratings (NHTSA/Safercar.gov).
- Used car prices by make-model-model year-series (NADA).
- Monthly retail gasoline prices in each county in CA (OPIS).
- Zip-code demographics (2000 Census).
- County-level monthly unemployment (BLS)
- Monthly Consumer Confidence Index (Conference Board)
- County-level monthly median house prices (CA Realtor's Association)

Summary Statistics

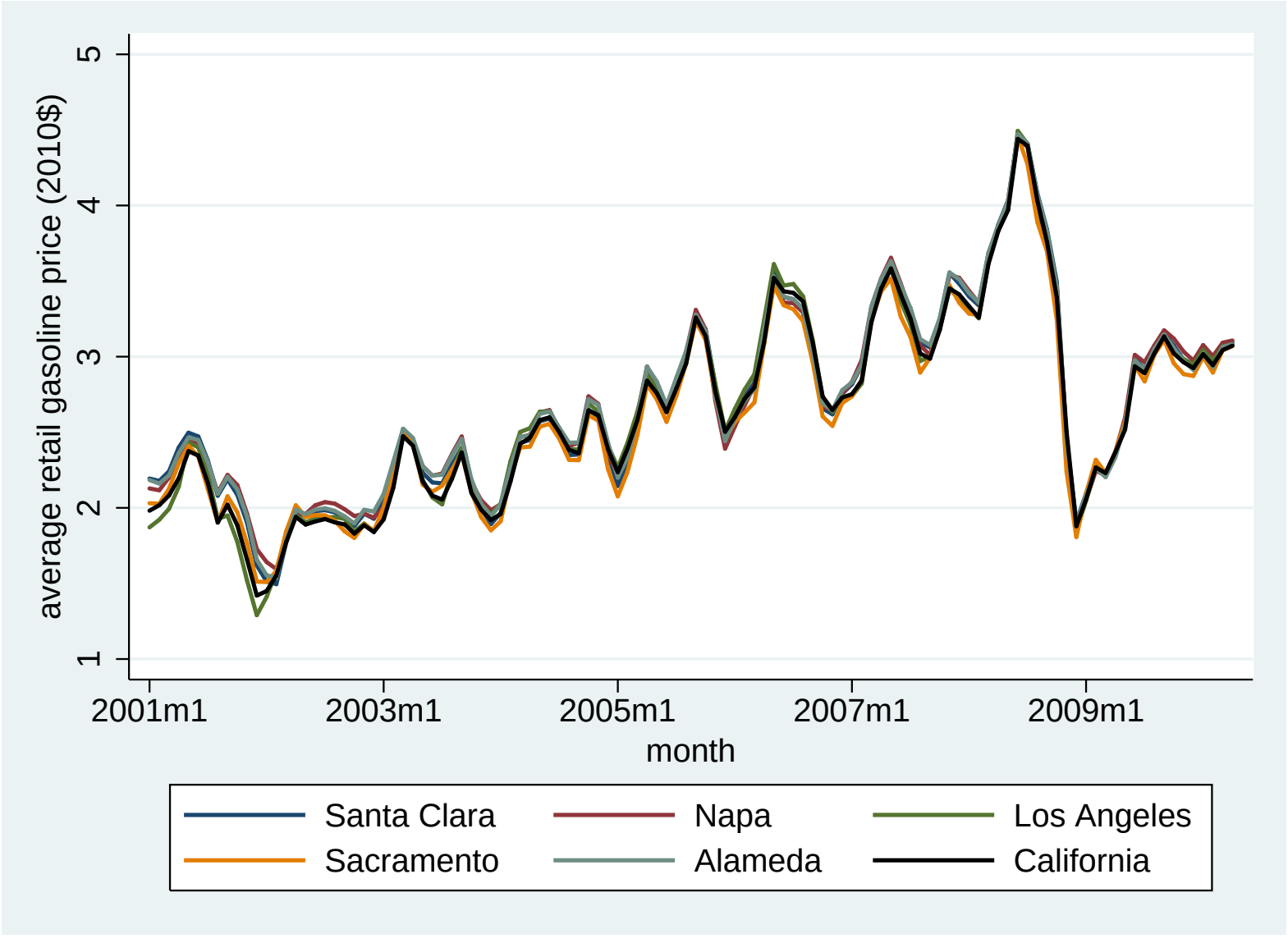
Table: Personal New Vehicle Dataset Summary Statistics

Variable	Mean	Std Dev	Min	Max	Observations
cylinders	5.81	1.56	2	16	12,334,583
liters	3.33	1.3	0.4	8.4	12,334,583
automatic transmission	0.96	0.21	0	1	12,334,583
gross veh weight rating (000s)	5.32	1.26	0.44	14.05	12,334,583
hybrid	0.02	0.15	0	1	12,334,583
import	0.66	0.47	0	1	12,334,583
safety rating	4.31	0.43	1	5	12,334,583
convertible	0.03	0.16	0	1	12,334,583
turbo	0.03	0.17	0	1	12,334,583
all-wheel drive	0.18	0.39	0	1	12,334,583
fuel economy 2008 ratings	19.22	5.72	8	50	12,334,583
vehicle MSRP (2010$)	29,709	12,492	9,034	1,500,000	12,334,583
months to smog test	69.31	10.87	13	107	4,652,064
VMT	1,088.68	464.95	0	4,993	4,652,064
income category	5.87	2.29	1	9	8,723,983
income (thousands $)	72.74	42.19	7.5	150	8,723,983
resale price of same model 6 yrs old	12,371.14	5948.68	1522	734,325	12,334,583
gas price at purchase (2010$)	2.6	0.63	1.25	5	12,334,583
avg gas price (2010$)	2.92	0.23	2.19	3.69	12,334,508
county unemployment rate	5.97	2	2.8	27.1	12,334,583
county house prices (000s $)	490.27	194.75	94.44	1195.37	12,334,583
consumer confidence index	93.51	18.53	25.3	118.9	12,334,583
avg unemployment rate	7.38	2.37	3.58	29.03	12,334,583
avg consumer conf index	78.84	15.35	47.04	104.36	12,334,508
avg housing prices	478.24	173.22	106.95	1072.55	12,334,583

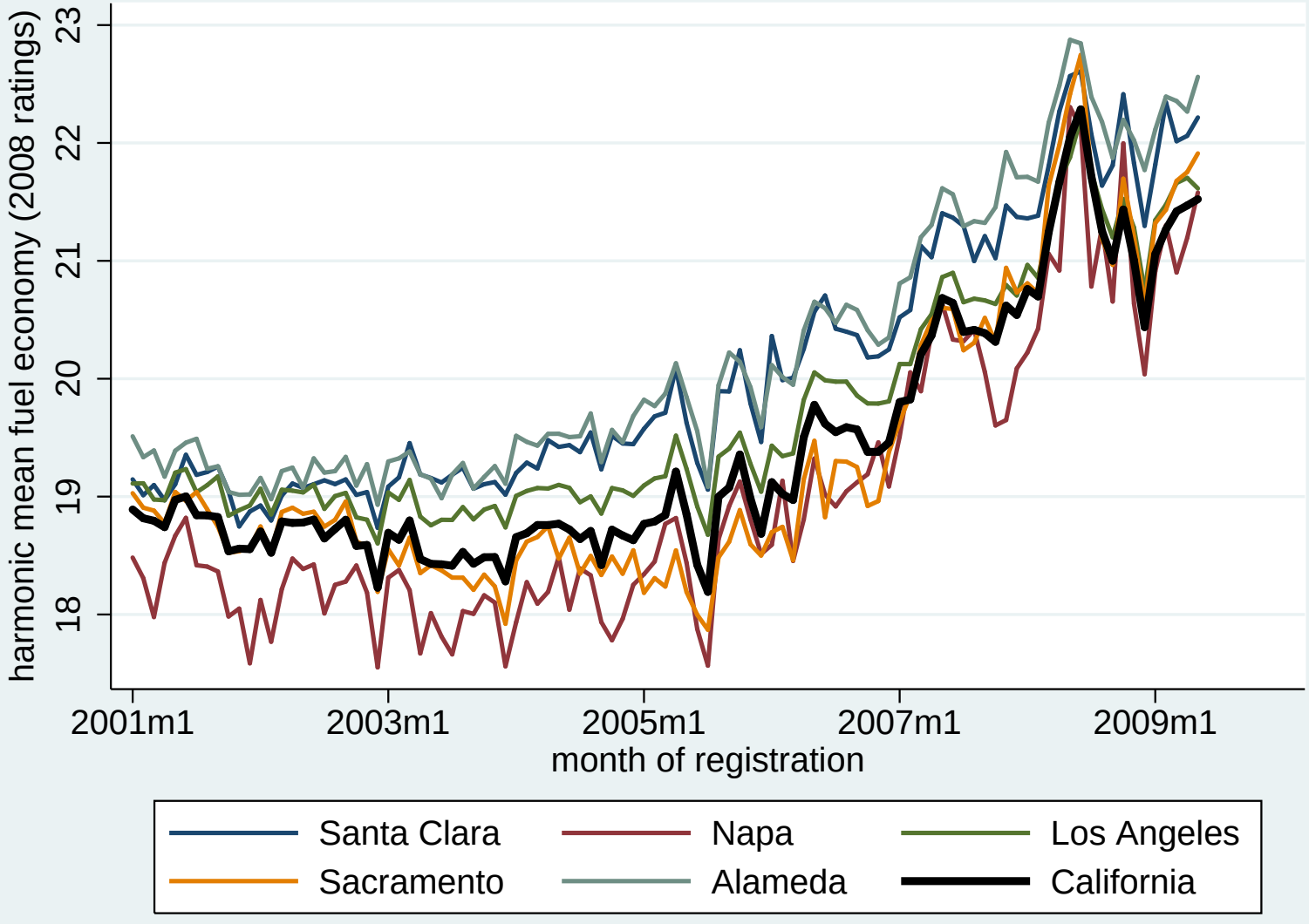
Note: harmonic mean given for fuel economy (arithmetic mean = 20.5), all-wheel drive includes four-wheel drive

The Backdrop: Changing Gasoline Prices

Considerable changes recently in retail gasoline prices:

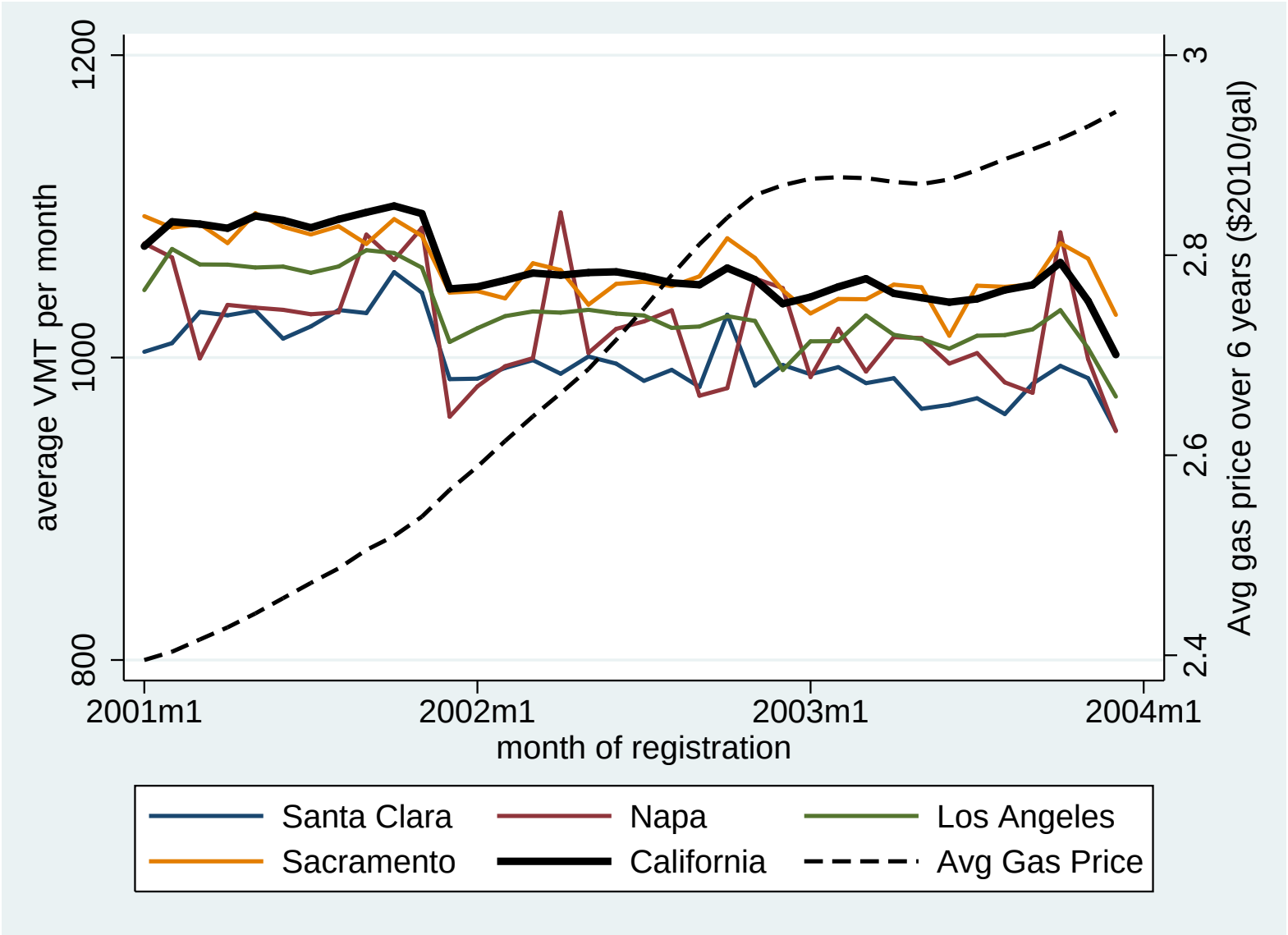


An Increase in New Vehicle Fuel Economy



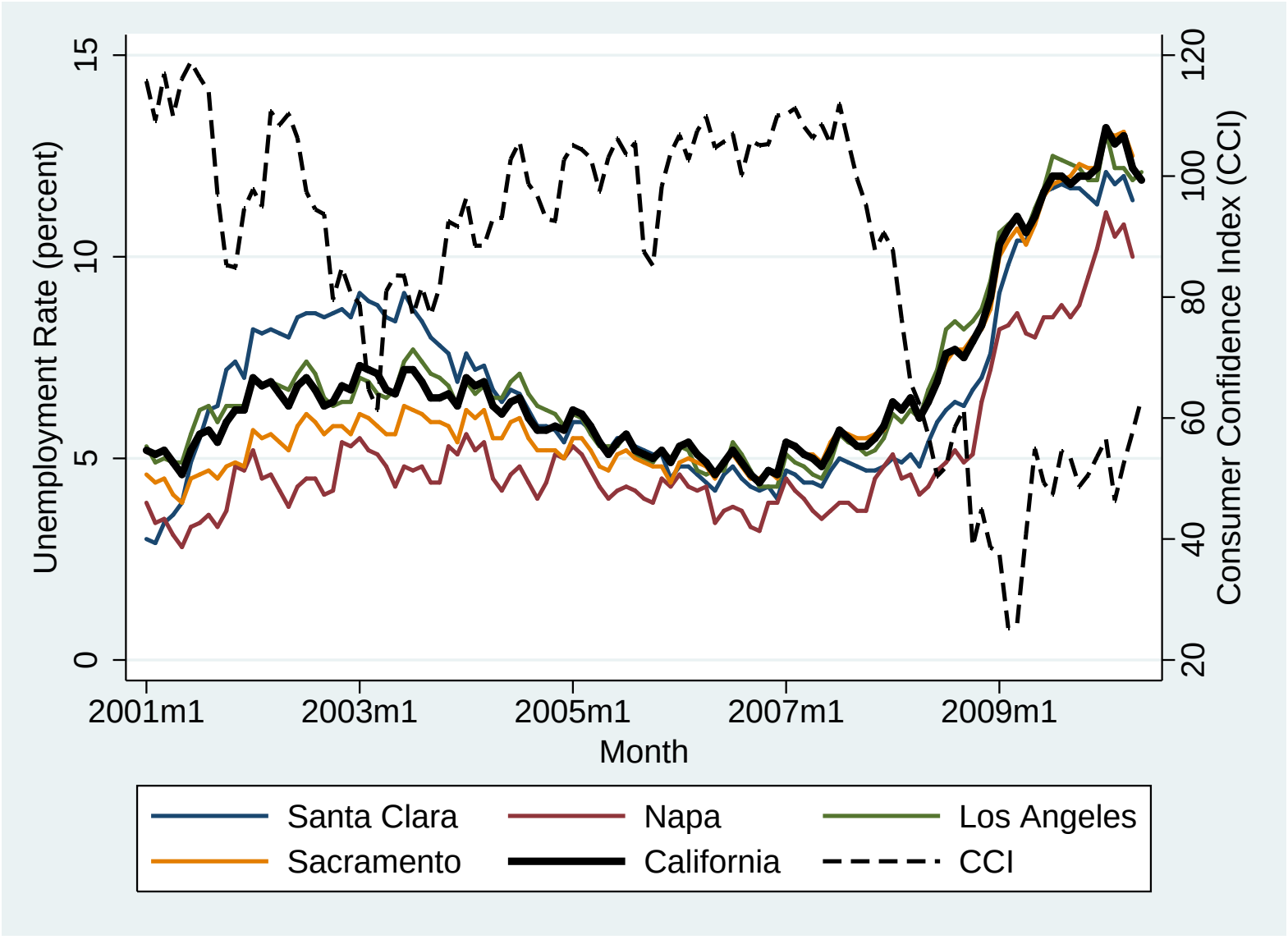
A Slight Decrease in Driving

Average VMT per month for vehicles registered in 2001-2004:



Economic Conditions Also Changed

Variation in unemployment & CCI:



Selection Into Different Vehicles

Consider model for VMT demand for consumer i driving vehicle j in time interval t:

$$VMT_{ijt} = \beta_0 + \beta_1 \left(\frac{p^g_{it}}{MPG_j(\eta)} \right) + \boldsymbol{\beta}_\theta \theta_j(\eta) + \boldsymbol{\beta}_x x_{ijt} + \varepsilon_{ijt}(\eta),$$

where

- $p^g_{it} \in \mathbb{R}^1$ is the price of gasoline,
- $MPG_j \in \mathbb{R}^1$ is the fuel economy of the vehicle,
- $\theta_j \in \mathbb{R}^\Theta$ is a vector of vehicle characteristics,
- $x_{ijt} \in \mathbb{R}^X$ is a vector of commute times, demographics, and economic conditions,
- η is the consumer's unobserved driving demand "type."

Model of Vehicle Choice and Utilization

- Two period model of consumer behavior:
  1. Consumers choose which vehicle to purchase.
  2. Consumers choose how much to drive that vehicle.
- Consumers know their "driving demand type" at time of purchase, but do not know the shocks that may influence their driving.

Utilization Choice

- Consumer i chooses how much to drive conditional on owning vehicle j.
- Weighs the benefits against the costs of driving.
- Second-period money-metric utility:

$$u_2 = \alpha_{ij}\left(VMT_i - \frac{\lambda}{2}VMT_i^2\right) - \frac{p_i^g}{MPG_j}VMT_i,$$

where

$$1/\alpha_{ij} = \tilde{\alpha}_{ij} = -(\beta_c C_i + \beta_d z_i^d + \beta_e E_i + \gamma_2 \theta_j + \eta_i),$$

and

- $C_i \in \mathbb{R}^1$ are commuting needs,
- $z_i^d \in \mathbb{R}^{\mathcal{D}}$ are demographics,
- $E_i \in \mathbb{R}^{\mathcal{E}}$ are economic conditions, and

Unobserved Preference for Driving "Type"

I model the unobserved preference for driving:

1. known at the time of purchase (η_i^k)
2. unknown at the time of purchase (η_i^u)

which are assumed to be additively separable:

$$\eta_i = \eta_i^k + \eta_i^u.$$

Conditional VMT

Assuming an interior solution, we have the optimal VMT for each consumer i conditional on owning j:

$$VMT_{ij}^{*} = \frac{1}{\lambda} - \frac{\tilde{\alpha}_{ij}}{\lambda}\left(\frac{p_i^g}{MPG_j}\right).$$

Vehicle Choice

In the first period, consumers weigh the expected benefits against the expected costs of purchasing a particular vehicle $j \in \mathcal{J}_i$:

$$u_1 = \int \left(\delta_1 u_2 + \gamma_1 \theta_j + \delta_2 p_j^R - p_j + \epsilon_{ij} \right) dG,$$

where

- p_j^R is the resale price of the vehicle in six years,
- p_j is the price of the vehicle,
- ϵ_{ij} is a mean-zero stochastic error term, and
- G is the joint CDF of consumer beliefs of future gasoline prices and economic conditions.

Vehicle Choice

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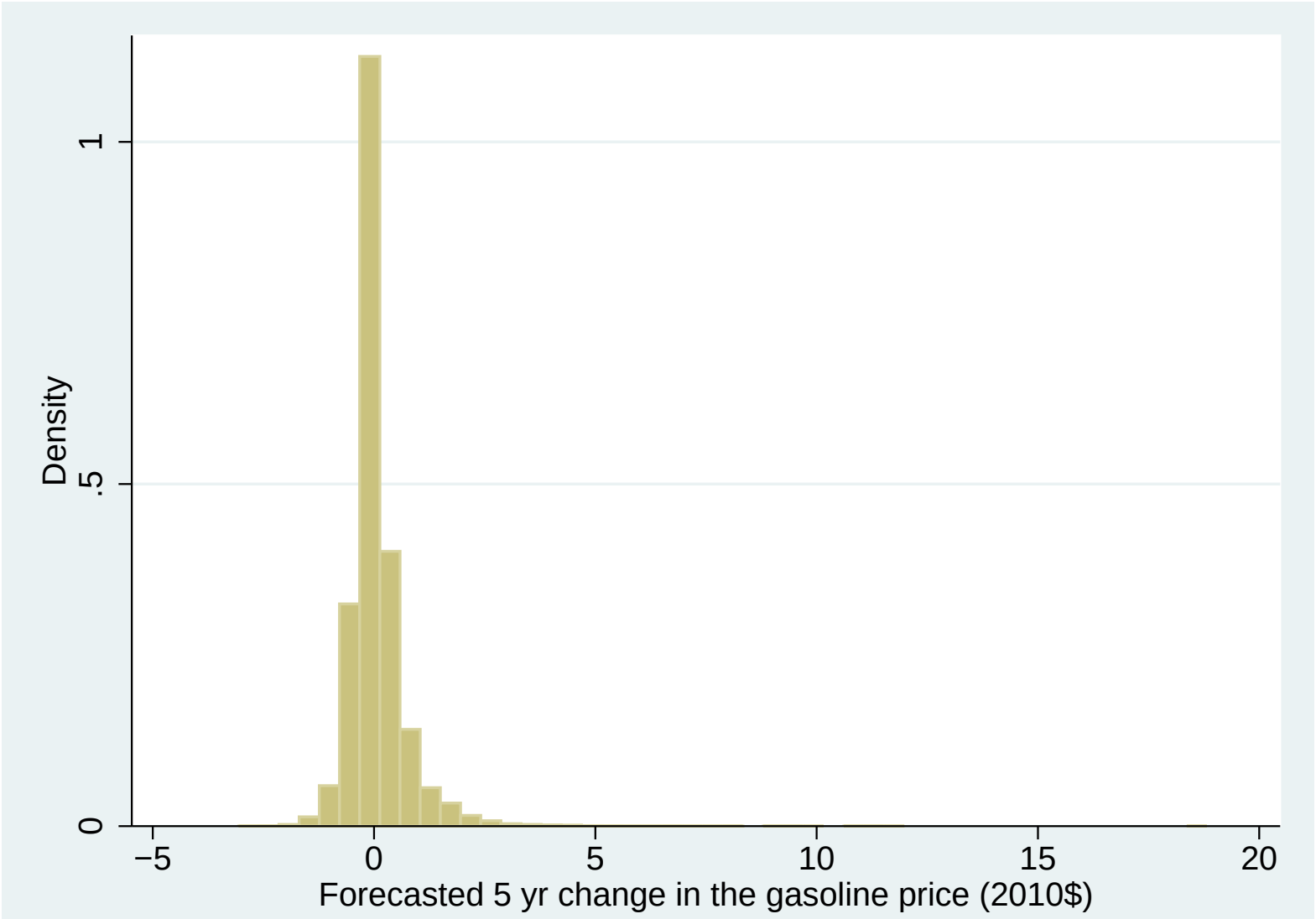
Expectation of Future Gasoline Prices

5 year consumer forecast of gasoline prices from Michigan Survey of Consumers (Anderson, Kellogg, and Sallee 2011):



Final Form of Period 1 Utility

The final form of period 1 utility is

$$u_1 = -\frac{\delta_1}{\lambda}\frac{\mathbb{E}[p_i^g]}{MPG_j} + \frac{\delta_1 \mathbb{E}[\tilde{\alpha}_{ij}]}{2\lambda}\frac{\text{var}(p_i^g) + \mathbb{E}[(p_i^g)]^2}{(MPG_j)^2} + \frac{\delta_1}{2\lambda}\mathbb{E}[\frac{1}{\tilde{\alpha}_{ij}}]$$
$$+ \gamma_1\theta_j - p_j + \delta_2(p_j^{R0} + \mu_j BM_j) - \frac{\delta_2\mu_j}{\lambda} + \frac{\delta_2\mu_j}{\lambda}\frac{\mathbb{E}[\tilde{\alpha}_{ij}]\mathbb{E}[p_i^g]}{MPG_j} + \epsilon_{ij}.$$

where

- $\mathbb{E}[\tilde{\alpha}_{ij}] = -(\beta_c C_i + \beta_d z_i^d + \beta_e \mathbb{E}[E_i] + \gamma_2\theta_j + \eta_i^k)$.

and $\mathbb{E}[p_j^R] = p_j^{R0} - \mu_j(\mathbb{E}[VMT_{ij}] - BM_j)$, with

- p_j^{R0} is the used car price with the baseline odometer reading, and
- μ_j is a pricing adjustment factor, and
- BM_j is the base mileage for the price adjustment.

Econometric Model

I assume the following stochastic structure for my model:

- $\epsilon_{ij} \sim$ i.i.d Type I extreme value
- $\eta_i^u \sim$ i.i.d $\mathcal{N}(0, \omega^2)$
- $\eta_i^k \sim$ i.i.d $\mathcal{N}(0, \sigma^2)$

Probability of Choosing Vehicle j

ϵ_{ij} being i.i.d Type I extreme value implies:

$$\Pr_i(j) = \frac{\exp(V_{ij})}{\sum_k \exp(V_{ik})},$$

where V_{ij} is the representative utility in period 1.

Unobserved Driving Type

The assumptions on η_i^k and η_i^u imply that $\eta_i \sim$ i.i.d $\mathcal{N}(0, \omega^2 + \sigma^2)$. Thus from our first-order condition,

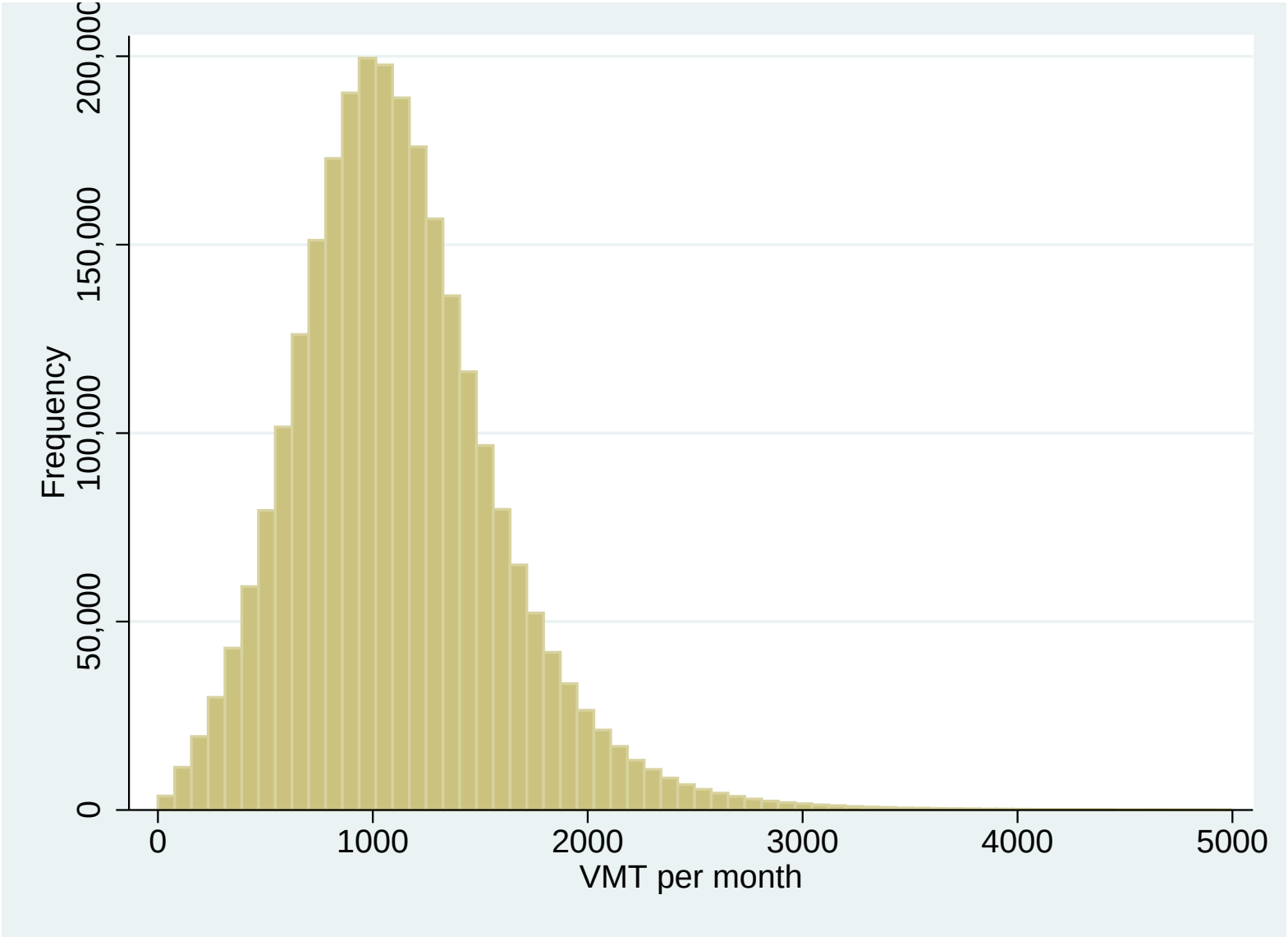
$$VMT_{ij}^* \sim \text{i.i.d } \mathcal{N}(\zeta_{ij}, \omega^2 + \sigma^2),$$

where

$$\zeta_{ij} = \frac{1}{\lambda} + \left(\frac{p_i^g}{\lambda MPG_j}\right)(\beta_c C_i + \beta_d z_i^d + \beta_e E_i + \gamma_2 \theta_j)$$

Empirical Distribution of VMT

The distribution looks close to a normal distribution



Conditional Likelihood Function

The conditional likelihood of a particular amount of driving by consumer i is thus

$$l(VMT_{ij}|j \text{ chosen}) = \frac{1}{\sqrt{2\pi(\omega^2+\sigma^2)}} \exp\left(-\frac{(VMT_{ij}-\zeta_{ij})^2}{2(\omega^2+\sigma^2)}\right).$$

So the conditional likelihood we observe the vehicle choices and utilization is

$$L_i = \int \prod_{j=1}^{J_i} \left(\Pr_i(j)\ l(VMT_{ij}|j \text{ chosen})\right)^{1_{ij}} dF_{\eta_i^k},$$

Estimation Strategy

- Use Maximum Simulated Likelihood (MSL).
  - Use 5,000 draws.
- The choice set $\mathcal{J}_i$ is all vehicle types in the quarter and county of the chosen vehicle.
- Impute missing VMT based on covariates (in primary results).
  - Also run it without imputation, losing vehicle purchase variation

Identification

- Exclusion restrictions:
  - Average gasoline price and economic conditions enter in period two.
- Control for local economic conditions and a variety of observables.
- Can include model FE (or a rich set of characteristics).
- Identification of vehicle choice is facilitated by the staggered timing of new models.
- Variation should be free of one selection issue:
  - Assuming imperfect foresight, purchases in 2001-2004 would not be taking the future gas price increase into account.

Descriptive Result on Intensive Margin: VMT Elasticity ∼ -0.2

Dependent variable: vehicle-miles-traveled per month (mean = 1,089 miles per month)

	(1) months-to-test	(2) econ cond	(3) mon-of-yr summer	(4) demog	(5) vehicle chars	(6) model FE
avg gasoline price	-110.7***	-62.8***	-62.8***	-78.8***	-69.6***	-69.3***
	(1.1)	(1.5)	(1.5)	(1.5)	(1.5)	(8.0)
avg unempl rate		-3.7***	-3.7***	-3.2***	-2.4***	-2.7***
		(0.2)	(0.2)	(0.2)	(0.2)	(0.5)
avg CCI		1.3***	1.4***	1.2***	1.2***	1.3***
		(0.1)	(0.1)	(0.1)	(0.1)	(0.2)
avg housing prices		-0.3***	-0.3***	-0.1***	-0.1***	-0.1***
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
commute time				5.4***	5.4***	5.4***
				(0.1)	(0.1)	(0.2)
fuel economy					2.6***	-1.3
					(0.1)	(2.3)
constant	1,357.8***	1,272.2***	1,214.7***	1,871.2***	1,558.8***	1,613.0***
	(3.0)	(9.8)	(11.4)	(17.6)	(17.5)	(68.2)
time-to-test FE	Y	Y	Y	Y	Y	Y
month-of-year FE	N	N	Y	Y	Y	Y
lease, race & age	N	N	N	Y	Y	Y
veh body & class	N	N	N	N	Y	Y
model FE	N	N	N	N	N	Y
Observations	4.65m	4.65m	4.65m	4.65m	4.65m	4.65m

*** indicates significant at 1% level, ** significant at 5% level
Robust standard errors in parentheses (clustered on model in (5),(6))

Descriptive Result on Extensive Margin: Fuel Economy Elasticity $\sim$ 0.1

Dependent Variable: fuel economy of new vehicles, harmonic mean = 19.2 mpg

	(1) base	(2) county FE	(3) time poly	(4) year FE	(5) county & year FE
gasoline price at purch	1.275***	1.579***	0.672***	0.583***	0.626***
	(0.003)	(0.004)	(0.005)	(0.005)	(0.005)
lease	-0.874***	-0.903***	-0.965***	-0.968***	-0.980***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
commute time	0.019***	-0.005***	0.019***	0.019***	-0.004***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
county unempl rate	0.005***	0.130***	-0.019***	-0.019***	-0.021***
	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)
consumer conf index	-0.019***	-0.007***	0.002***	-0.004***	-0.003***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
county housing prices	0.000***	-0.002***	0.001***	0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
registration month			6.495***		
			(0.156)		
(registration month)^2			-0.013***		
			(0.000)		
(registration month)^3			0.000***		
			(0.000)		
constant	20.1***	26.8***	-1,072.0***	22.6***	28.3***
	(0.086)	(0.107)	(27.879)	(0.087)	(0.108)
zip demogs	Y	Y	Y	Y	Y
Observations	12.3m	12.3m	12.3m	12.3m	12.3m

*** indicates significant at 1% level, ** significant at 5% level
Robust standard errors in parentheses (clustered on year in (4),(5))

Selected Structural Model Coefficient Estimates

VMT elasticity wrt the price of gasoline = -0.15*** (0.001)

β coefficients			γ coefficients		
zip density	-0.164***	(0.001)	γ_1 convertible	778.3***	(101.5)
commute	0.196***	(0.002)	γ_1 hybrid	2,772.9***	(70.2)
\$30,000 - \$39,999	-0.044	(0.031)	γ_1 gross wt rating	49.72***	(3.7)
\$40,000 - \$49,999	0.090***	(0.008)	γ_1 import	494.5***	(92.5)
\$50,000 - \$74,999	0.100***	(0.002)	γ_1 fuel economy	39.30***	(8.7)
\$75,000 - \$99,999	0.196***	(0.001)	γ_2 convertible	-0.106*	(0.06)
\$100,000 - \$124,999	0.082***	(0.000)	γ_2 hybrid	0.053***	(0.00)
>\$125,000	-0.178***	(0.003)	γ_2 gross wt rating	-0.082***	(0.01)
lease	-0.008**	(0.003)	γ_2 import	0.050***	(0.00)
λ	0.027***	(0.000)	unemployment	-0.132***	(0.014)
ω	0.013	(0.052)	CCI	0.272***	(0.109)

Robust standard errors in parentheses

*** denotes significant at 1% level, ** significant at 5% level, * significant at 1%

Robustness Checks

I perform a variety of robustness checks:

- Use a 5% and 10% discount rate
  - Makes very little change to either of the elasticity results
- Run the model on only the observations that are complete (no data imputation)
  - Lose much of the variation in fuel economy & gasoline prices
  - Find: VMT elasticity almost exactly the same, fuel economy elasticity is 0.07
- Use different assumptions about consumer expectations of future gasoline prices
  - Forecast extrapolating previous 6 months
  - Forecast using the mean of the previous 6 months

Effect of Selection

To examine importance of selection, I run each period separately:

- The VMT specification is linear and can be estimated with OLS.
  - An estimated mean elasticity of -0.21*** (0.001).
- The vehicle choice estimation can be performed with MSL.
  - Nearly the same estimated elasticity of 0.09*** (0.03).

Illustrative Counterfactual Policy Simulations

Counterfactual analysis of a gas tax that raises the price of gasoline by $1 per gallon:

- Driving decreases by 4.9% on average (elasticity of -0.15).
- Fuel economy of new vehicles increases by 3.4% on average (elasticity of 0.09).

Counterfactual analysis of a $50,000 per gal per mi revenue-neutral feebate policy:

- Driving increases by 1% for all new vehicles (rebound effect $\sim$ 0.06)
  - Only 43% of new vehicle buyers change which vehicle they buy.
  - The new vehicles also have different characteristics.
- Fuel economy of all new vehicles increases by 15% on average.

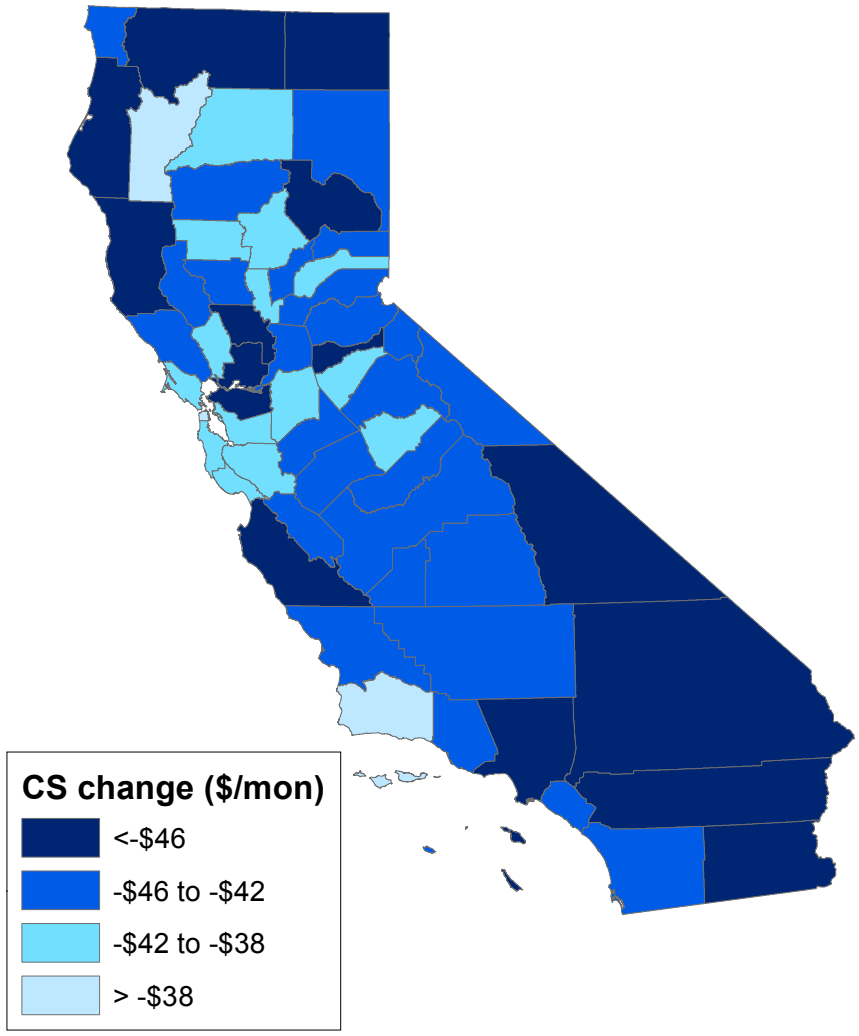
Illustrative Welfare Consequences

Examining vehicles in 2002 cohort and ignoring externalities:

- Gasoline Tax:
  - Change in period-two consumer surplus = -$510 per vehicle/yr.
  - Government tax revenues from consumers = $480 per vehicle/yr.
  - Change in period-one consumer surplus = -$3.7 per vehicle.
- Revenue-neutral Feebate Policy:
  - Change in period-two consumer surplus = $11 per vehicle/yr.
    - Change if gasoline prices held constant = -$18 per vehicle/yr.
  - Change in period-one consumer surplus = -$5.6 per vehicle.

Preview: Distributional Consequences of Gasoline Tax

Consumer impacts before revenue recycling.



Conclusions

- Evidence of responsiveness on both margins:
  - Gasoline price elasticity of driving of -0.15 for new personal vehicles.
  - Gasoline price elasticity of fuel economy around 0.1.
- Selection appears to bias the elasticity of driving.
- Estimate of direct rebound effect from this feebate appears to be small.
- Policy implications:
  - Significant cuts in CO_2 emissions from transport would likely require a high carbon price.
  - Direct rebound effect from standards is not likely to be a dominant concern.

Work-in-progress

I have follow-on work-in-progress in several directions:

- This project: Add in consumer beliefs, model outside option, instrument for MSRP
- Estimating the "Prius effect" using Mass data
- Development of a fully dynamic model of vehicle choice
  - with John Rust et al. using Danish data
  - with David Rapson using California data
- The demographic and geographic distributional consequences of gasoline tax
- The cost per ton of carbon of a gasoline tax versus feebate/CAFE standard

Thank you for your thoughts!

Acknowledgments

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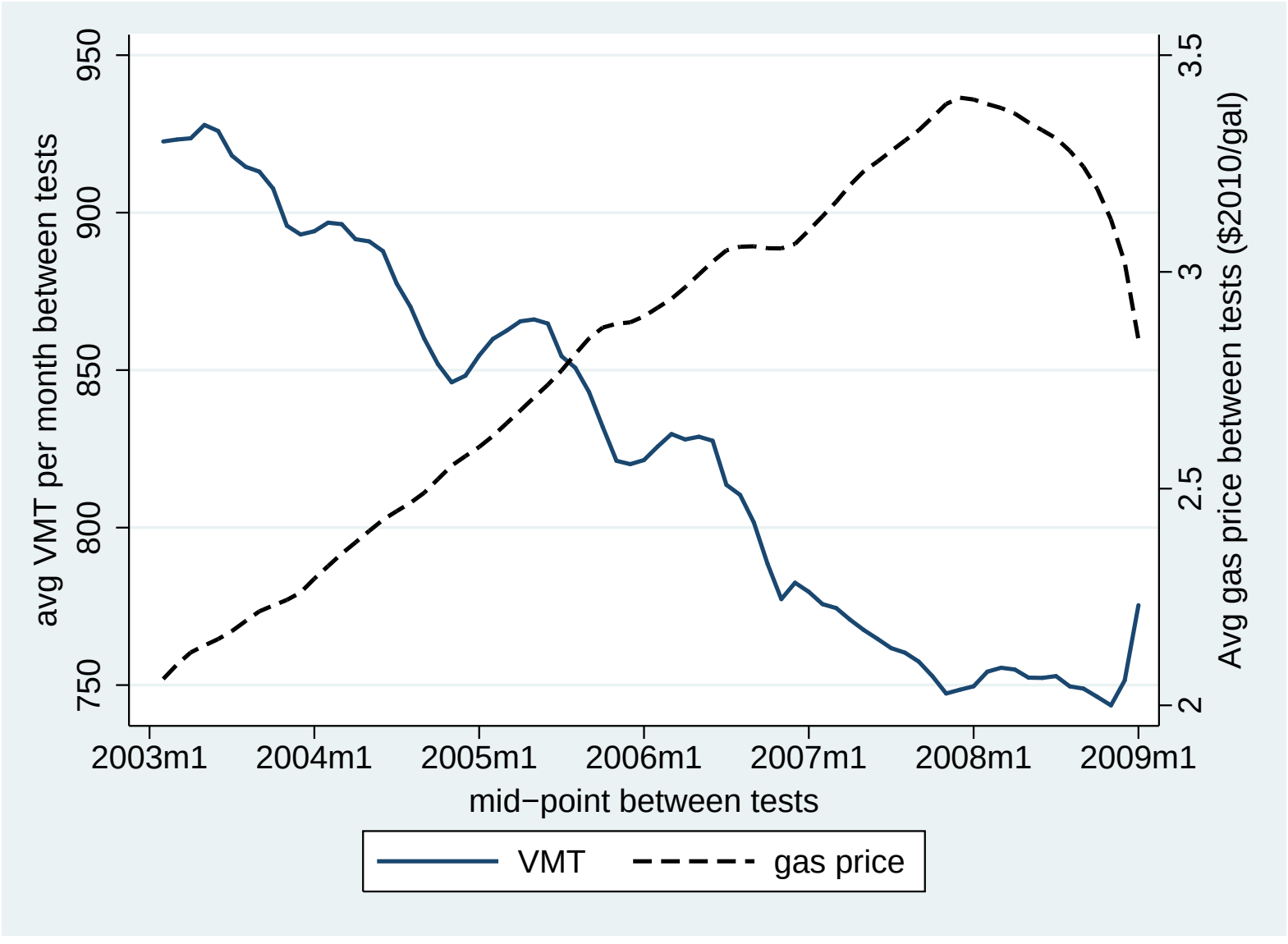
- I would also like to thank the generous funding from the SIEPR Shultz Fellowship program, the Precourt Energy Efficiency Center, and the EPA STAR Fellowship program.

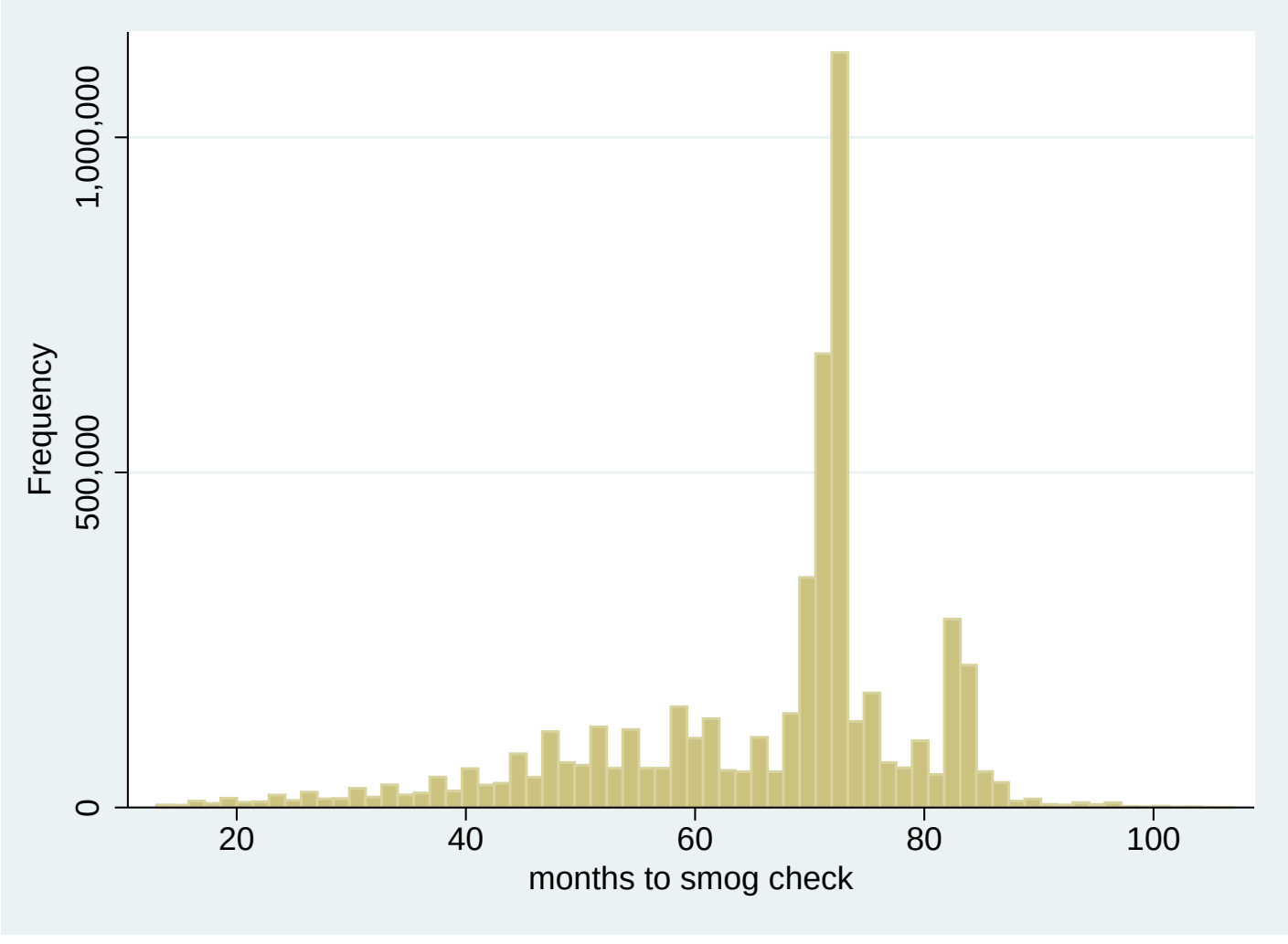
Appendix: Evidence of a Decrease in Driving

For "older" vehicles with smog checks 2002-2009:



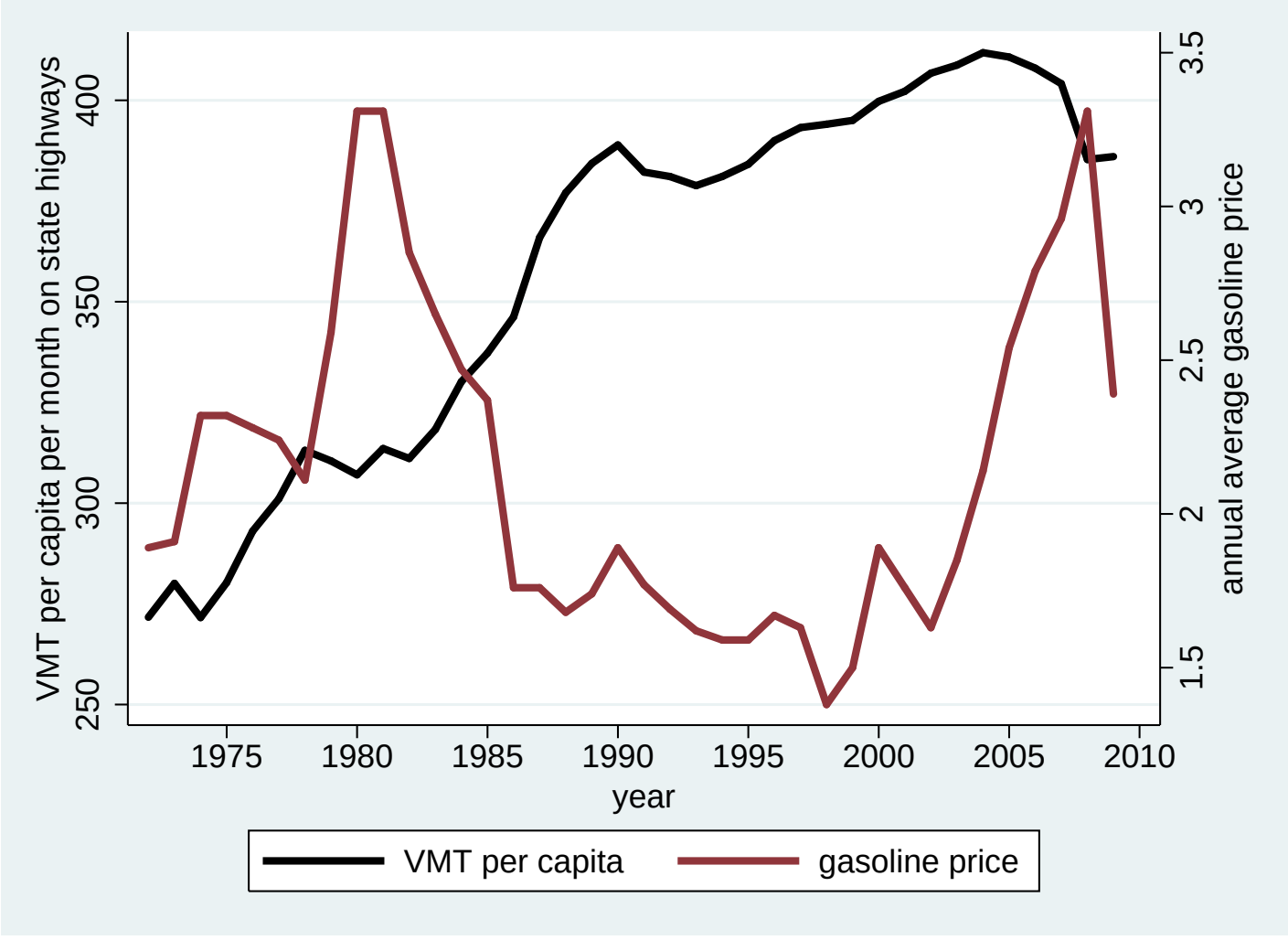
Appendix: Most Smog Checks at 6 Years

Histogram of months from registration to first test for personal purchases:



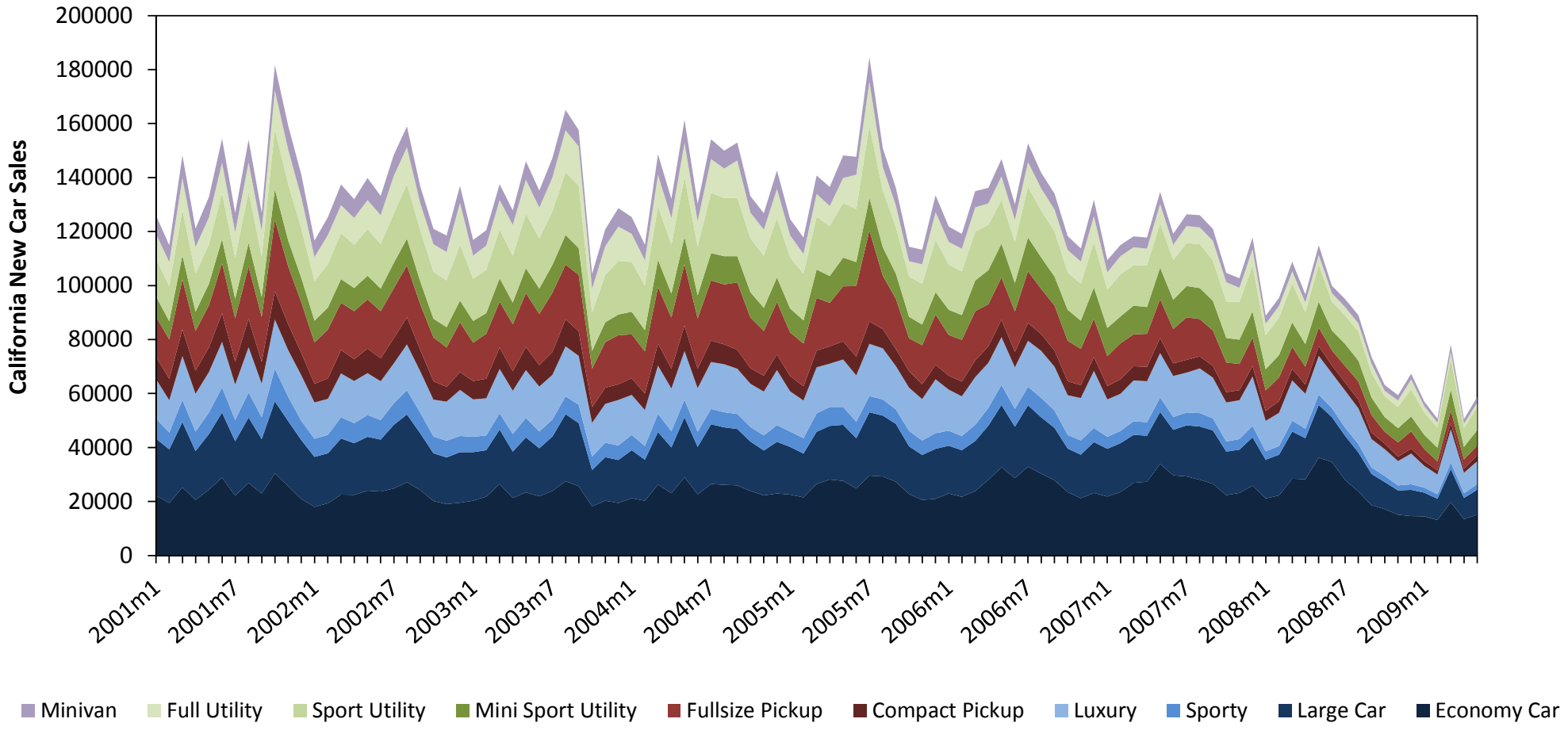
Appendix: Long Term Trend in VMT per Capita

There has been a long-term upwards trend in VMT per capita:



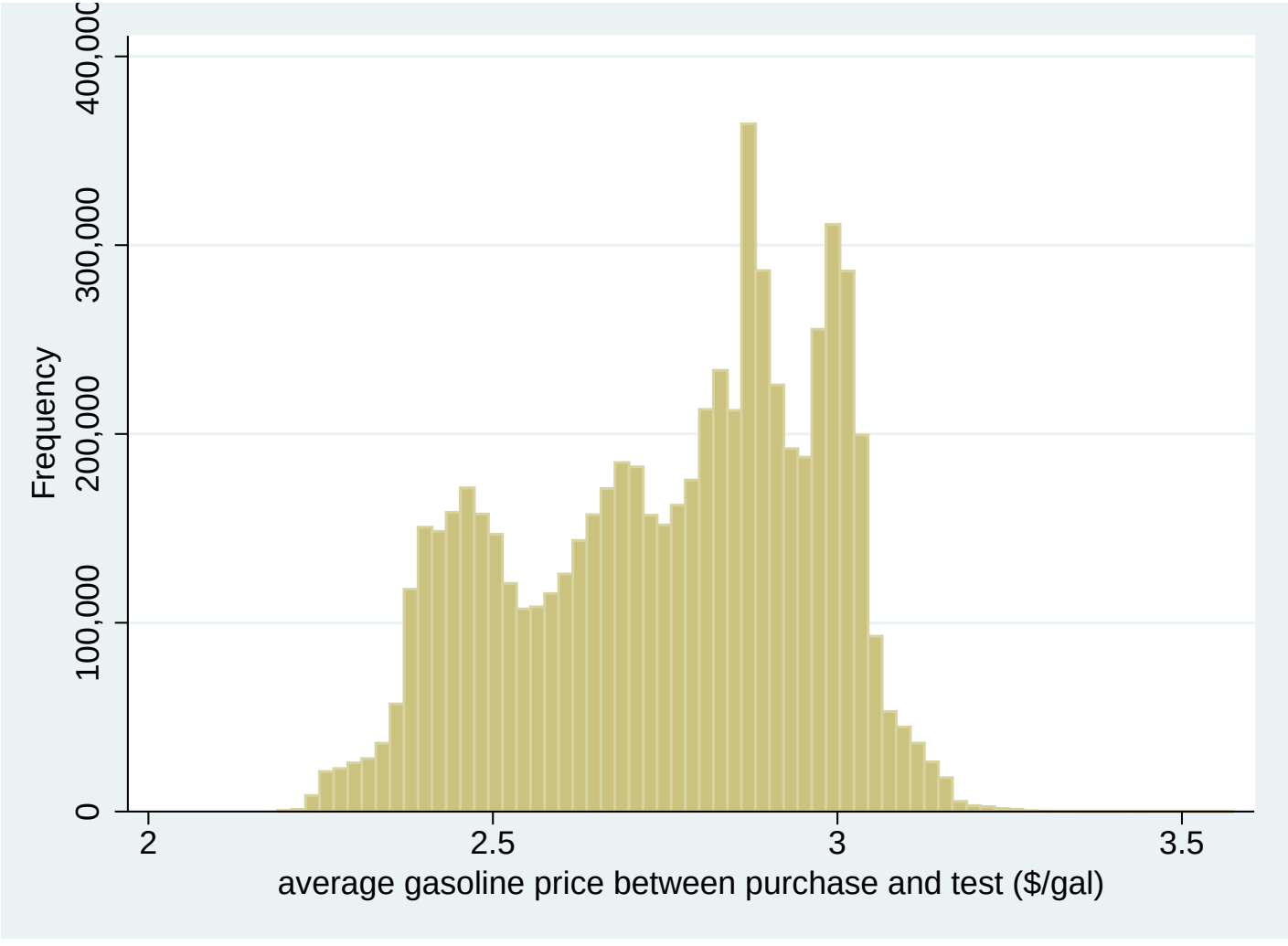
Appendix: Monthly Auto Sales

Sales of new autos changed quite a bit over this period:



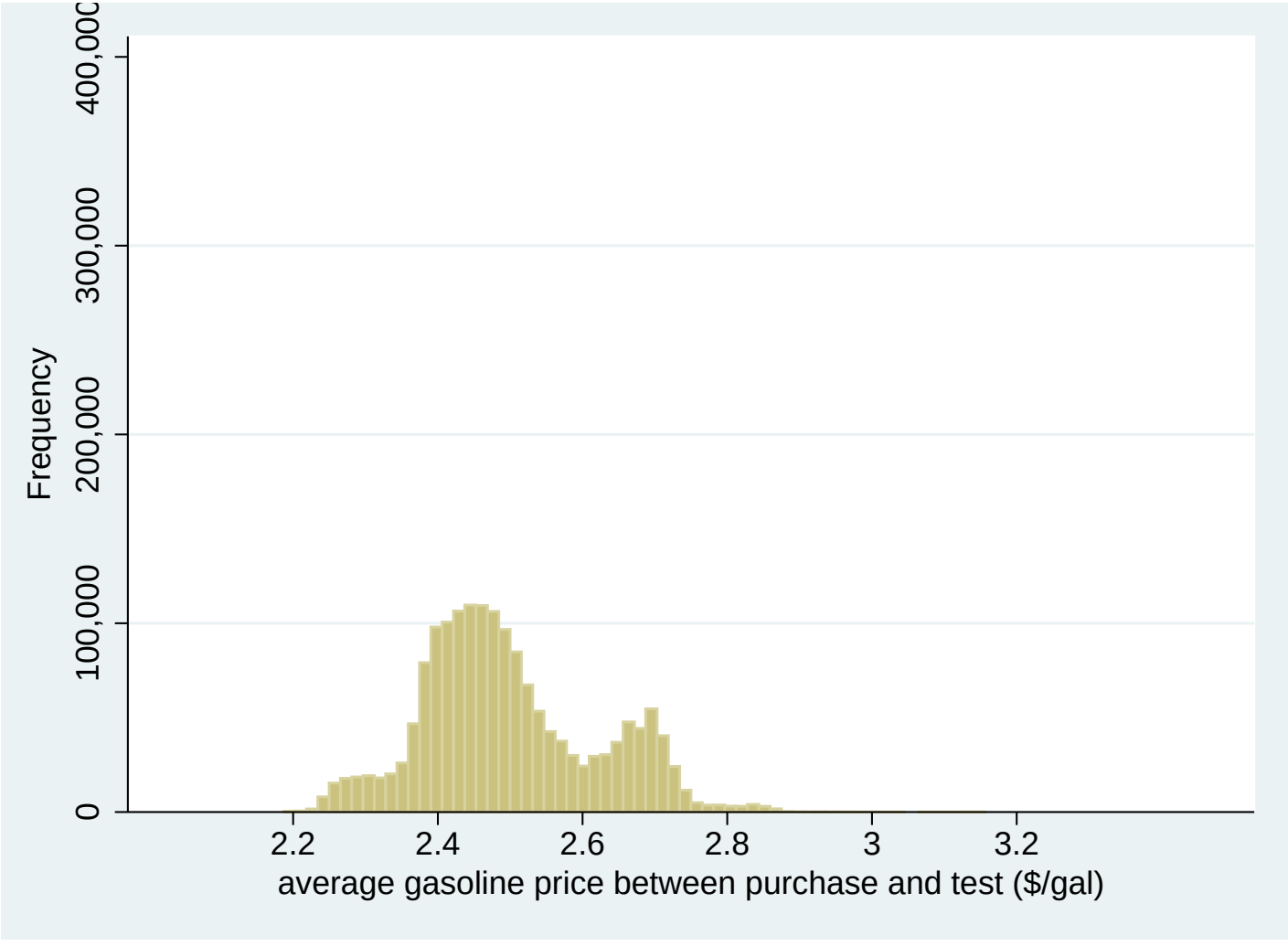
Appendix: Variation in Average Gas Prices

Histogram of average gas prices 2001-2004:



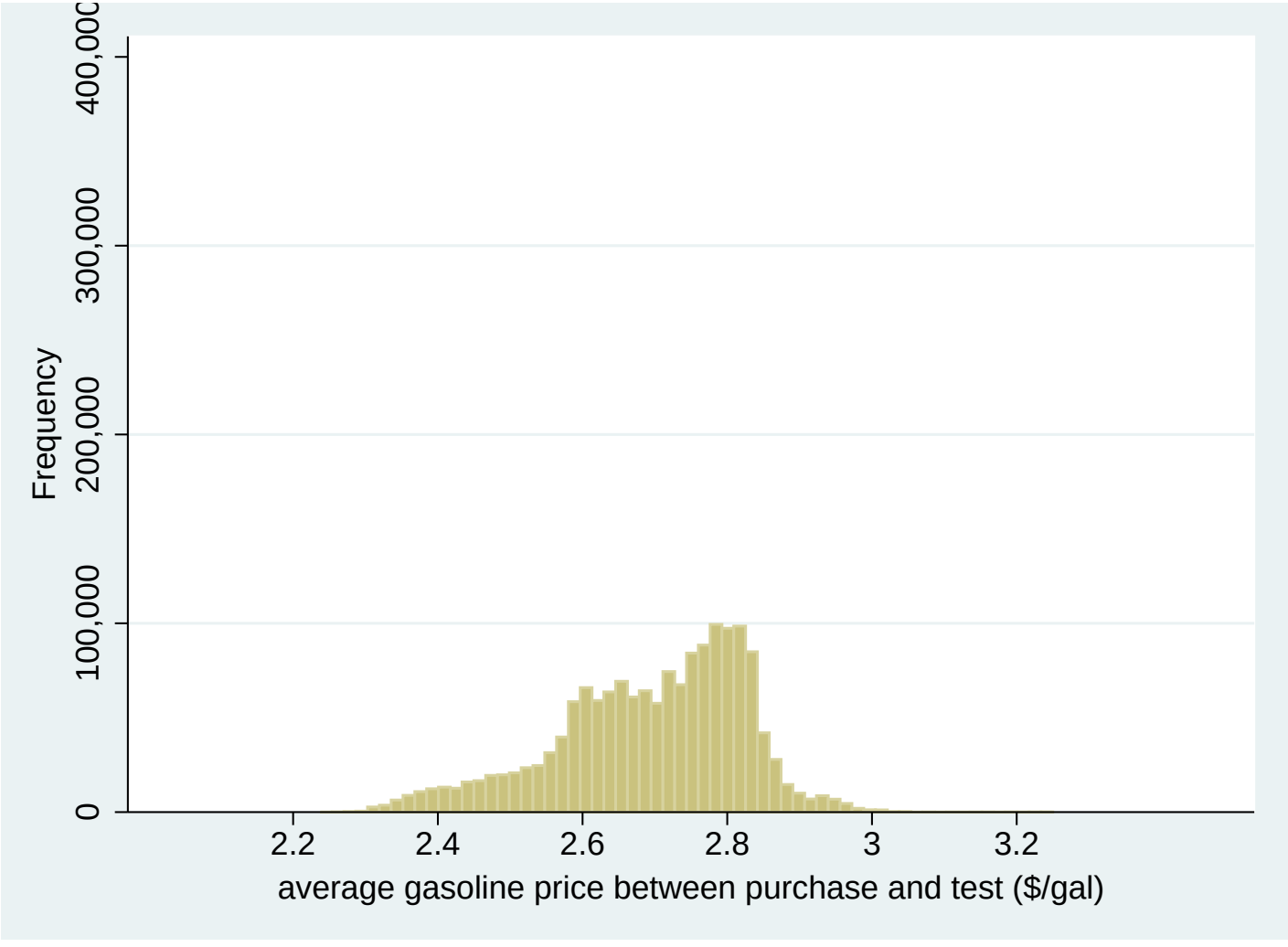
Appendix: Variation Both Within and Across Years

Histogram of average gas prices 2001:



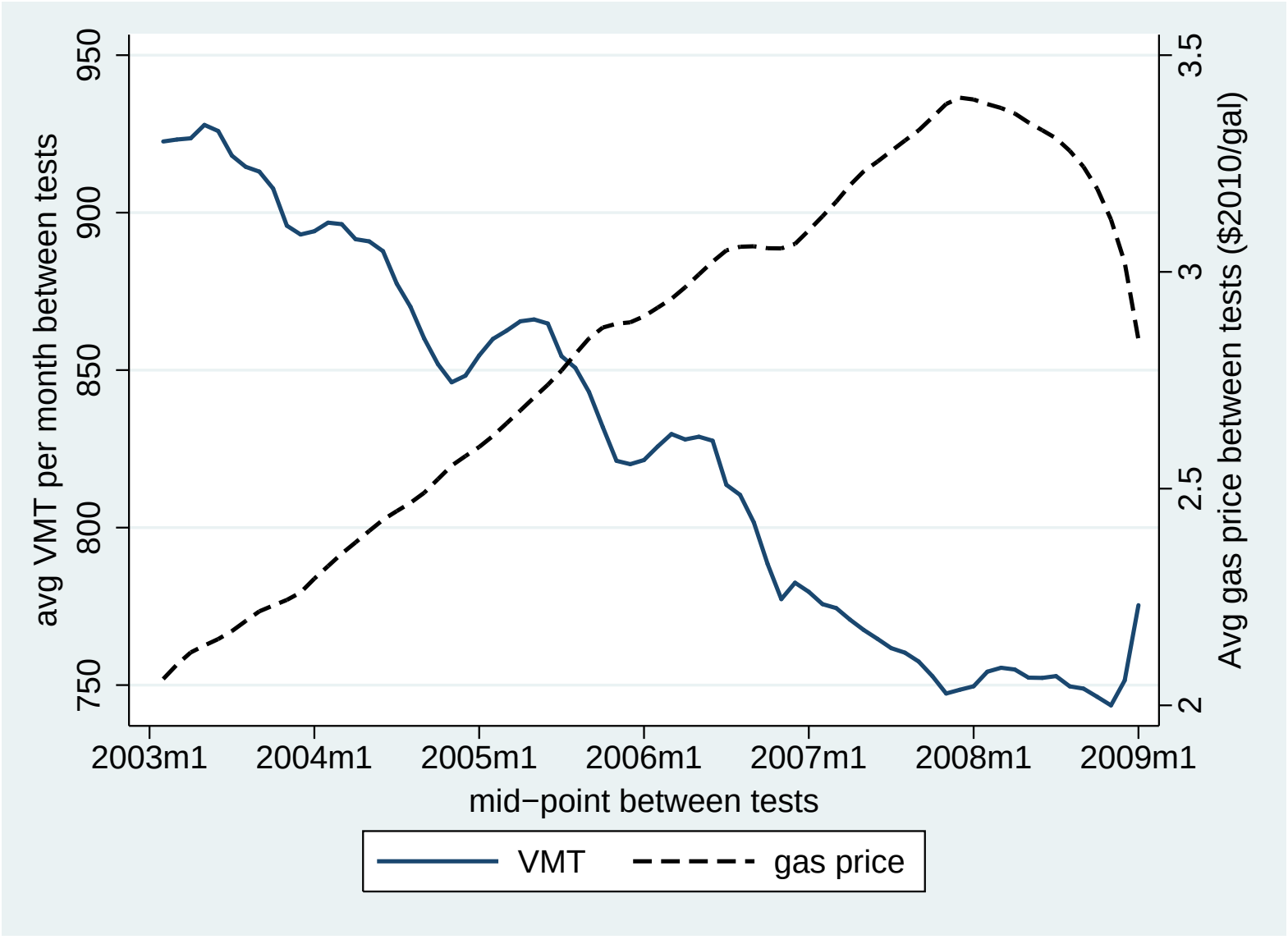
Appendix: Variation Both Within and Across Years

Histogram of average gas prices 2002:



Appendix: Evidence of a Decrease in Driving

For "older" vehicles with smog checks 2002-2009:



Appendix: Expected Resale Price

Assume consumers use the price of the same vehicle model six years old as expected resale price. Let

$$\mathbb{E}[p_j^R] = p_j^{R0} - \mu_j(\mathbb{E}[VMT_{ij}] - BM_j),$$

where

- p_j^{R0} is resale price at time of vehicle purchase,
- μ_j is a pricing adjustment factor, and
- BM_j is the base mileage for the price adjustment.

Appendix: Demographic Summary Statistics

Table: Demographic Summary Statistics

Variable	Mean	Std Dev	Min	Max	Observations
zip density (000/mi^2)	5.08	5.5	0	52.18	12,334,583
commute time 2000(min)	27.1	4.28	13.4	43.1	12,334,583
zip businesses 2000	1,510.74	957.96	1	6,521	12,334,583
zip businesses/capita	0.05	0.59	0	104.82	12,334,583
zip population 2007	41,404.93	20,470.53	1	109,549	12,334,583
zip pop growth rate 00-07	1.77	3.1	-32.5	199.2	12,334,583
zip median hh income 2007	70,633.08	27,370.53	0	375,000	12,334,583
zip % pop age 65+	11.14	5.29	0	100	12,334,583
zip % pop under 18	25.73	6.06	0	41.3	12,334,583
zip % pop white 2007	59.66	18.55	4.4	100	12,334,583
zip % pop black 2007	5.15	7.45	0	86.60	12,334,583
zip % pop hispanic 2007	31.93	21.46	0	97.8	12,334,583

Appendix: Evidence of Heterogeneity by Vehicle Class

Dependent variable: vehicle-miles-traveled per month (mean = 1,089 miles per month)

	Vehicles (000s)	fuel economy (mi/gal)	coefficient	s.e.	elasticity at means	s.e.
All Vehicle Classes	4,652	18.6	-69.6***	(1.5)	-0.172***	(0.004)
Small Cars	771	26.4	-37.9***	(2.9)	-0.094***	(0.007)
Large Cars	723	21.9	2.2	(3.0)	0.005	(0.007)
Sporty Cars	198	20.7	-153.3***	(5.1)	-0.379***	(0.013)
Prestige Sporty	60	18.5	-21.4***	(7.7)	-0.053***	(0.019)
Luxury	444	19.9	-59.9***	(3.2)	-0.148***	(0.008)
Prestige Luxury	99	17.7	-54.5***	(6.1)	-0.135***	(0.015)
Pickup	287	17.4	-118.1***	(5.0)	-0.292***	(0.012)
Full Pickup	523	14.7	-154.1***	(3.9)	-0.381***	(0.010)
Sport Utility	914	17.3	-53.2***	(2.5)	-0.132***	(0.006)
Full Utility	395	13.6	-134.0***	(3.7)	-0.331***	(0.009)
Minivan	238	18.3	-69.5***	(4.8)	-0.172***	(0.012)

Heteroskedasticity-robust standard errors in parentheses
*** indicates significant at 1% level, ** significant at 5% level, * significant at 10% level

Appendix: Evidence of Heterogeneity by Income

Dependent variable: vehicle-miles-traveled per month (mean = 1,089 miles per month)

	Vehicles (000s)	coefficient	s.e.	elasticity at means	s.e.
All Income	2,332	-94.9***	(2.4)	-0.244***	(0.006)
$15k - $20k	67	-26.8***	(7.2)	-0.069***	(0.018)
$20k - $30k	172	-27.7***	(5.6)	-0.071***	(0.014)
$30k - $40k	196	-28.3***	(7.7)	-0.072***	(0.015)
$40k - $50k	223	-26.5***	(6.2)	-0.068***	(0.016)
$50k - $75k	568	-23.3***	(6.4)	-0.060***	(0.016)
$75k - $100k	391	-24.8***	(5.0)	-0.064***	(0.017)
$100k - $125k	206	-24.6***	(6.7)	-0.063***	(0.017)
>125k	344	-20.9***	(6.7)	-0.054***	(0.017)

Heteroskedasticity-robust standard errors in parentheses
*** indicates significant at 1% level

Appendix: Next Step on Data Augmentation

I only observe VMT for the first four years of the dataset.

- Use a data augmentation approach developed by Erdem, Keane, and Sun (1999) for missing prices/coupons in scanner data.
- Idea: discretize VMT so that $VMT_{ij} \in \{VMT_1, ..., VMT_L\}\ \forall i, j$.
- Let the probability consumer i purchasing j chooses VMT_l be ρ_{ijl}, where

$$\rho_{ijl} = \frac{exp\left\{a_1 VMT_l + a_2 VMT_l^2 + a_3 VMT_l^3 + a_4 VMT_l^4\right\}}{A} \ \forall\ l.$$

- Then can sum over the highly flexible estimated joint distribution of VMT at the end.