# How do Household Drivers Respond to a Tax on Vehicle Miles Traveled?

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Camp Resources XXI

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# What Do We Do?

- How do consumers respond to a tax on Vehicle Miles Travel (VMT)?
- Empirical challenge: there are (almost) no taxes on VMT
- Two solutions:

1. Toll roads as a proxy for VMT pricing
2. Oregon experimented with a pilot VMT tax program

# Motivation

- Externalities from Automobiles/Driving (Parry et al. 2007, JEL)
  - Pollution
  - Global warming
  - Oil dependency/national security
  - Traffic congestion
  - Traffic accidents

Pollution, Global warming, Oil dependency/national security: Gasoline-dependent

Traffic congestion, Traffic accidents: VMT-dependent

- Optimal policy includes a tax on gasoline and a tax on VMT
- We know a lot about consumers' response to gasoline taxes
  - Intensive margin – miles traveled
  - Extensive margin – fuel economy of vehicle
- Less is known about consumers' response to VMT taxes (no empirical data under VMT tax)

# What Do We Find?

- Drivers in states with a higher proportion of toll roads drive significantly less and drive significantly more fuel-efficient cars
- Correlation between MPG and VMT is different for Oregon drivers subject to a VMT tax than for those subject to a gas tax
  1. In the expected direction
  2. Small sample; noisy data

# What does the literature tell us?

- Direct tax on vehicle emission is not cost-effective (Fullerton and West 2010)
- Taxing fuels is compromised by agent’s driving less with gas guzzlers (Greene 2011)
- Fuel Economy standard (CAFE) is compromised by agent’s driving more with fuel efficient cars (Greene 2008)
- Tax on VMT, has been on policy makers’ table and drawn congressional attention (McMullen, Zhang et al. 2010, Greene 2011), can correct rebound effects
- VMT tax alone will not provide efficient instrument to correct most of the automobile externalities (Caroll-Larson and Caplan, 2009)
- VMT tax will be slightly more regressive than the fuel tax, rural households benefit relative to urban households under a VMT tax (McMullen et al. 2010)
- A VMT tax schedule - Indexed Roadway User Toll on Energy (IRoUTE) (Greene 2011)

# Our suggestion

- **VMT tax on top of Fuel Tax**
  - Discourage (excessive) driving
  - Encourage choice of fuel efficient cars

# Why is it important?

- Theoretical model of optimal policy under gas externalities and VMT externalities
- First-best: tax each at marginal damage, no need to know demand elasticity
- Second-best: if only one instrument (e.g. a gas tax) to target both externalities, need to know the elasticity
  - Gasoline tax only
    - $\tau_g = -\frac{u_A A'}{\lambda} - \frac{u_T T'}{\lambda} \cdot mpg \cdot \left(1 + \frac{\eta_{mpgg}}{\eta_{gg}}\right)$
      - Where $\eta_{mpgg} \equiv \frac{dmpg}{d\tau_g} \frac{\tau_g}{mpg}$ and $\eta_{gg} \equiv \frac{dg}{d\tau_g} \frac{\tau_g}{g}$
      - $u_A$: marginal utility on gasoline related externality
      - $u_T$: marginal utility on VMT related externality
  - VMT tax only
    - $\tau_m = -\frac{u_A A'}{\lambda} \left( \frac{mpg}{1 + \frac{m \cdot dmpg}{mpg \cdot dm}} \right) - \frac{u_T T'}{\lambda}$

# Data

- State-year-level toll road data from US DOT Highway Statistics
  - Year 2009
  - % of total road-miles that are tolled – proxy for VMT tax (cost)
- State level fuel price data from US DOE Energy Information Administration
- Combine with vehicle-level micro data from 2009 National Household Travel Survey (NHTS)
  - 134571 vehicles, 112130 non-missing data records
  - Miles traveled
  - Household demographic characteristics – age, gender, race, price of gasoline

# Empirical Model – Toll Road Data

**On vehicle-level data**

$$vmt_i = a_0 + \alpha_1 \cdot toll_i + a_2 \cdot p_i + \boldsymbol{\alpha} \cdot X_i + \epsilon_i$$

$$mpg_i \quad = \beta_0 + \beta_1 \cdot toll_i + \beta_2 \cdot p_i + \boldsymbol{\beta} \cdot X_i + \mu_i$$

Where

$toll_i$: the ratio of toll road miles to total road miles in vehicle $i$'s state,

$p_i$: the tax-inclusive price of fuel faced by vehicle $i$

$X_i$ is a vector of state, household, driver characteristics

# Summary Statistics

| Level | Variable | N | mean | Std. dev. | minimum | median | Maximum |
|---|---|---|---|---|---|---|---|
| state | Toll Road Miles% | 50 | 0.1367 | 0.2303 | 0 | 0.0027 | 0.8626 |
| | State Has Toll Road | 50 | 0.54 | 0.5035 | 0 | 1 | 1 |
| | Total Road Miles (k miles) | 50 | 80.98 | 53.927 | 4.37 | 80.658 | 310.85 |
| | Price of Gasoline, regular grade | 50 | 2.271 | 0.1388 | 2.076 | 2.2428 | 2.843 |
| vehicle | Est. Annual VMT | 132396 | 11183.41 | 7655.972 | 0 | 9842.11 | 50000 |
| | Gasoline eq. MPG | 132204 | 21.305 | 6.311 | 5.9 | 20.6 | 117 |
| | Household income level | 124158 | 11.329 | 5.4537 | 1 | 12 | 18 |
| | Household size | 134571 | 2.376 | 1.2274 | 1 | 2 | 13 |
| | Number of Vehicles in Household | 134571 | 2.136 | 1.0758 | 0 | 2 | 27 |
| | Age of driver | 121097 | 57.586 | 15.7855 | 15 | 58 | 92 |
| | Household in Urban | 134570 | 0.705 | 0.4561 | 0 | 1 | 1 |
| | Race of Driver | 134571 | 0.871 | 0.335 | 0 | 1 | 1 |
| | Female Driver | 121097 | 0.597 | 0.4906 | 0 | 1 | 1 |

Education Level

| Highest Grade completed | Frequency | % |
|---|---|---|
| Less than high school | 7137 | 5.30 |
| High school graduate | 31194 | 23.18 |
| Some college | 35020 | 26.02 |
| College graduate | 26548 | 19.73 |
| Graduate or Professional degree | 20135 | 14.96 |
| *Missing* | 14537 | 10.80 |

# Model Estimates

$$vmt_i = a_0 + \alpha_1 \cdot toll_i + a_2 \cdot p_i + \boldsymbol{\alpha} \cdot X_i + \epsilon_i$$

| Parameter | Annual VMT | | | |
|---|---|---|---|---|
| Intercept | 11034.58 (177.569)** | 16200.93 (1311.776)** | 22059.47 (456.369)** | 21989.86 (456.742)** |
| Toll Road Miles% | -996.16 (523.176) | -1035.27 (402.873)* | -518.92 (149.584)* | |
| Std. Toll Road Miles% | | | | -118.73 (34.225)* |
| Price of Gasoline, regular grade | | -2363.42 (583.915)** | -3229.35 (198.197)** | -3229.35 (198.197)** |
| Total Road Miles (k miles) | | 1.405 (0.6416)* | 1.376 (0.3811)** | 1.376 (0.3811)** |
| *Household Characteristics and Driver Demographics*[a] | | | Yes[b] | Yes[b] |

Note: Clustered robust standard error in parentheses
Statistically significant at: * 0.01 level, ** < 0.001 level
[a]: Predictors are: Household income levels, Household size, Number of Vehicles in Household, Household in Urban, Race of Driver, Age of driver, Female Driver, and Education Levels.
[b]: All are statistically Significant at 0.001 level.

# Model Estimates

$$mpg_i = \beta_0 + \beta_1 \cdot toll_i + \beta_2 \cdot p_i + \boldsymbol{\beta} \cdot X_i + \mu_i$$

| Parameter | EIA Derived Gasoline-equivalent MPG | | | |
|---|---|---|---|---|
| Intercept | 21.07<br>(0.059)** | 12.28<br>(0.992)** | 17.03<br>(0.966)** | 17.13<br>(0.954)** |
| Toll Road Miles% | 0.67<br>(1.005) | 0.71<br>(0.400) | 0.75<br>(0.325)* | |
| Std. Toll Road Miles% | | | | 0.17<br>(0.074)* |
| Price of Gasoline, regular grade | | 4.04<br>(0.438)** | 3.28<br>(0.445)** | 3.28<br>(0.445)** |
| Total Road Miles (k miles) | | -0.003<br>(0.0004)** | -0.003<br>(0.0005)** | -0.003<br>(0.0005)** |
| *Household Characteristics and Driver Demographics*[a] | | | YES[b] | YES[b] |

Note: Clustered robust standard error in parentheses
Statistically significant at: * 0.01 level, ** < 0.001 level
[a]: Predictors are: Household income levels, Household size, Number of Vehicles in Household, Household in Urban, Race of Driver, Age of driver, Female Driver, and Education Levels.
[b]: All are statistically Significant at 0.001 level.

# Oregon Road Usage Charge Program

- Oregon pilot VMT tax program

  1. To provide supported evidence for replacing fuel tax by VMT tax in raising highway maintenance fund
  2. Vehicle owners are charged by miles driven in lieu of fuel tax
  3. Two pilot studies

     1) Road User Fee Pilot Project: 2006 - 2007;
     2) Road Usage Charge Pilot Project: 2012 - 2013

# Oregon VMT tax pilot data

- Data of pilot 2012-2013 from the office of Road User Charge Program, Oregon DOT
  1. Vehicle type, model, year
  2. Odometer (miles) readings before and after program
- Empirical strategy: Regress VMT on vehicle fuel economy (MPG), separately for those (small number) in the VMT tax pilot program and for all other Oregon drivers from the NHTS
- Hypothesis: for those facing VMT tax instead of gas tax, the correlation between VMT and MPG is weaker

# Summary Statistics

## Oregon Road Charge Program Data

### In-program Vehicles vs NHTS Vehicles

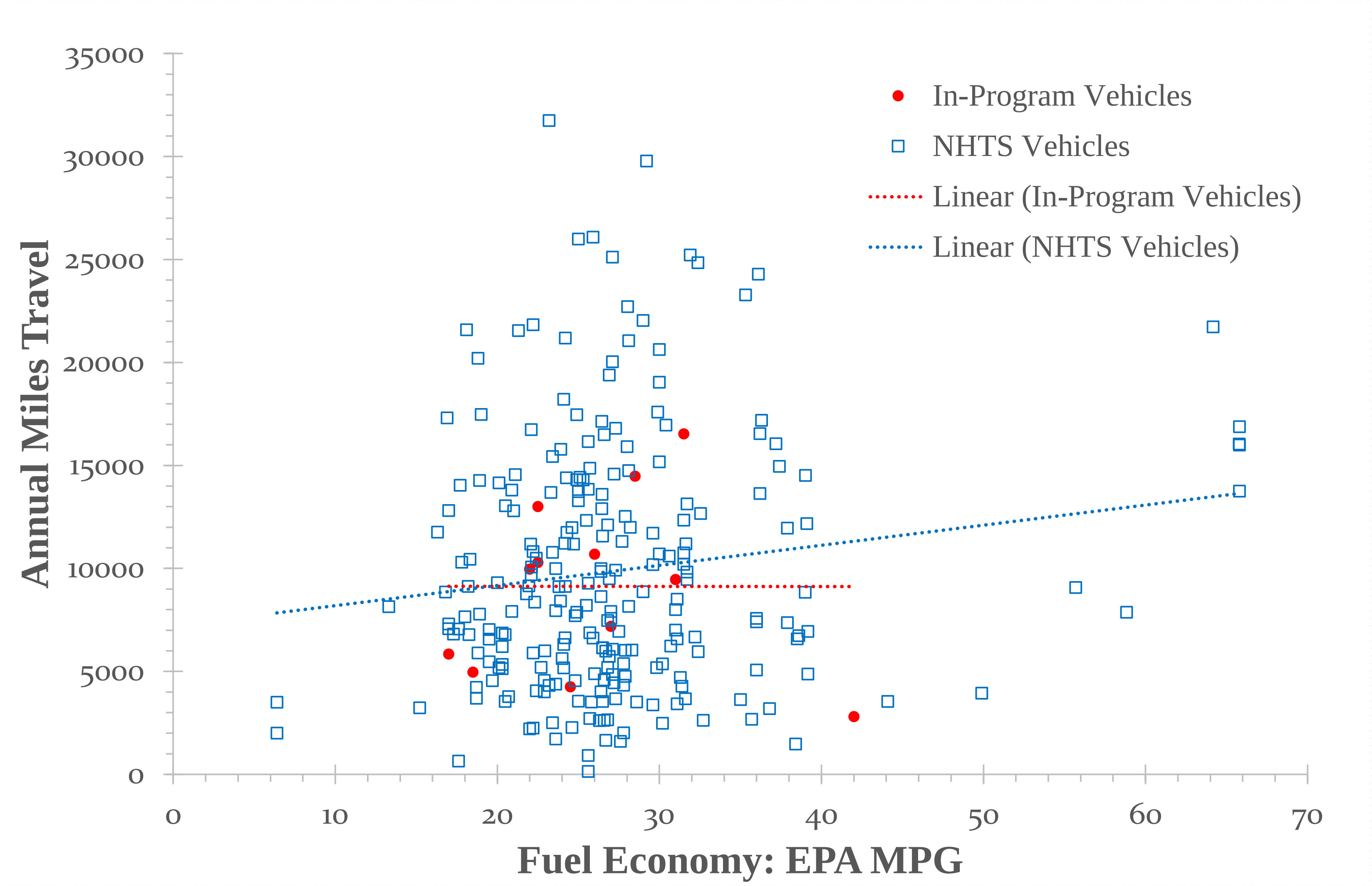
| | In-program Vehicles | | | 2009 NHTS Vehicles | | |
|---|---|---|---|---|---|---|
| | n/N [b] | Mean | Std. dev. | N | mean | std dev |
| Annual VMT | 12/45 | 9013.3[a] | 4438.30 | 238 | 9881.1 | 6085.49 |
| EPA MPG | | 26.08 | 6.731 | | 27.29 | 8.675 |

Note [a]: Normalized to a year

[b]: N – total number of participants, n – number of participants with available data

# Correlation between VMT and MPG,

## VMT-tax pilot group vs NHTS data



# Correlation between VMT and MPG,

## VMT-tax pilot group vs NHTS data

| Correlation coefficients (p-values) | In program Vehicles | | 2009 NHTS Vehicles | |
|---|---|---|---|---|
| | Annual VMT | EPA MPG | Annual VMT | EPA MPG |
| Annual VMT | 1.0 | -0.00045 (0.9989) | 1.0 | 0.13950 (0.0315) |
| EPA MPG | | 1.0 | | 1.0 |

Those drivers facing VMT tax instead of gas tax, the correlation between VMT and MPG is weaker

# Conclusion

- Toll road data give some (weak) evidence that consumers respond in the expected way to VMT pricing
- Oregon pilot data analysis yields "expected" result
  - Suffered small, biased sample
- Extensions
  - Toll data at MSA level, more years
  - Toll rates
  - Leased cars as proxy for VMT pricing
  - VMT pricing in Singapore, Hong Kong

# Acknowledgement

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- Questions?
- Comments?

**Thank You!**

# Appendix

# Economic Models

Agent's utility:

$$U(m, g)$$

Where:

$g$ consumption of gasoline/fuel,

$m$ is the number of vehicle miles traveled (VMT),

$U_m > 0$ $U_{mm} < 0$, $U_g > 0$, $U_{gg} < 0$, $U_{mg} > 0$

# Economic Models

Agent's utility:

$$U = u(c, m, A, T)$$

Where:

*c* consumption of a numeraire good,

*m* is the number of vehicle miles traveled (VMT),

*A* is a public good (externality) related to gasoline consumption

(e.g. air quality or climate change),

*T* is a public good (externality) related to VMT

(e.g. traffic congestion or the accident rate)

# Economic Models

The agent's budget constraint is

$$y = c + g \cdot (p_g + \tau_g) + mpg \cdot g \cdot \tau_m + f(mpg) - r$$

Where:

$p_g$ : gasoline price (an exogenous)

$t_g$ : gasoline tax

$\tau_m$ : VMT tax

*mpg:* fuel economy in miles per gallon

*g:* gasoline consumption

*m:* miles drive, $m = g \cdot mpg$

$r$ : transfer to the consumer from the government

$$\tau_m \cdot m + \tau_g \cdot g = r$$

# Economic Models

## Agent's Choice:

Value function

$$V(\tau_g, \tau_m, r, A, T)$$

$$= \max_{m,g,mpg,c} u(m, c, A, T) + \mu[m - mpg \cdot g] + \lambda[y - c - g \cdot (p_g + \tau_g) - m \cdot \tau_m + r - f(mpg)]$$

FOCs

$$u_m = u_c \cdot \frac{p_g + \tau_g}{mpg} + u_c \cdot \tau_m$$

$$f'(mpg) = (p_g + \tau_g) \cdot \frac{g}{mpg}$$

# Economic Models

The second-best gasoline tax sets $\frac{dV}{d\tau_g}$ equal to zero. It is

$$\tau_g = -\frac{u_A A'}{\lambda} - \frac{u_T T'}{\lambda} \cdot mpg \cdot \left(1 + \frac{\eta_{mpgg}}{\eta_{gg}}\right)$$

where $\eta_{mpgg} \equiv \frac{dmpg}{d\tau_g}\frac{\tau_g}{mpg}$ is the elasticity of $mpg$ demand with respect to the gasoline tax and

$\eta_{gg} \equiv \frac{dg}{d\tau_g}\frac{\tau_g}{g}$ is the elasticity of gasoline demand with respect to the gasoline tax.

# Economic Models

Social Planer problem

$$\frac{\partial V}{\partial \tau_g} = -\lambda \cdot g$$

$$\frac{\partial V}{\partial \tau_m} = -\lambda \cdot m$$

$$\frac{\partial V}{\partial r} = \lambda$$

$$\frac{\partial V}{\partial A} = u_A$$

$$\frac{\partial V}{\partial T} = u_T$$

$$\tau_g \cdot dg + g \cdot d\tau_g + \tau_m \cdot mpg \cdot dg + \tau_m \cdot g \cdot dmpg + g \cdot mpg \cdot d\tau_m = dr.$$

$$dV = \lambda \tau_g dg + \lambda \tau_m mpg \cdot dg + \lambda \tau_m g \cdot dmpg + u_A A' \cdot dg + u_T T' \cdot (g \cdot dmpg + mpg \cdot dg)$$

$$\tau_g = -\frac{u_A A'}{\lambda}$$

$$\tau_m = -\frac{u_T T'}{\lambda}$$

# Full Model Estimates

| Parameter | Estimated Annual Miles | | | |
|---|---|---|---|---|
| Intercept | 11283.10<br>(26.6495)**** | 16125.57<br>(431.5565)**** | 22029.55<br>(484.2398)**** | 21980.77<br>(482.3286)**** |
| Toll Road Miles$ | -637.954<br>(104.6890)**** | -733.101<br>(105.6111)**** | -363.594<br>(111.0038)** | |
| Std. Toll Road Miles$ | | | | -83.192<br>(25.3981)** |
| Price of Gasoline, regular grade | | -2280.38<br>(190.5238)**** | -3189.04<br>(200.9196)**** | -3189.04<br>(200.9196)**** |
| Total Road Miles (k miles) | | 1.994<br>(0.2618)**** | 1.673<br>(0.2740)**** | 1.673<br>(0.2740)**** |
| Household income level | | | 182.602<br>(5.0872)**** | 182.602<br>(5.0872)**** |
| Household size | | | 536.517<br>(22.3347)**** | 536.517<br>(22.3347)**** |
| Number of Vehicles in Household | | | -72.403<br>(23.7840)** | -72.403<br>(23.7840)** |
| Household in Urban | | | -1442.18<br>(49.7188)**** | -1442.18<br>(49.7188)**** |
| Race of Driver | | | 253.561<br>(68.9695)*** | 253.561<br>(68.9695)*** |
| Age of driver | | | -93.305<br>(1.7181)**** | -93.305<br>(1.7181)**** |
| Female Driver | | | -767.702<br>(44.9659)**** | -767.702<br>(44.9659)**** |
| Education Level [a] | | | | |
| Less than high school | | | -665.642<br>(114.0987)**** | -665.642<br>(114.0987)**** |
| High school Graduate | | | -693.476<br>(74.2620)**** | -693.476<br>(74.2620)**** |
| Some college | | | -167.143<br>(69.6961)* | -167.143<br>(69.6961)* |
| College degree | | | -296.355<br>(71.0943)**** | -296.355<br>(71.0943)**** |

a: compared to Graduate and professional degree
Significant level: * at 0.05; **: at 0.01; ***: at 0.001; ****: < 0.0001

# Full Model Estimates

| Parameter | EIA Derived Gasoline-equivalent MPG | | | |
|---|---|---|---|---|
| Intercept | 21.177<br>(0.0220)**** | 12.204<br>(0.3551)**** | 16.986<br>(0.4114)**** | 17.115<br>(0.4098)**** |
| Toll Road Miles% | 0.821<br>(0.0863)**** | 1.020<br>(0.0869)**** | 0.964<br>(0.0943)**** | |
| Std. Toll Road Miles% | | | | 0.221<br>(0.0216)**** |
| Price of Gasoline, regular grade | | 4.123<br>(0.1568)**** | 3.332<br>(0.1707)**** | 3.332<br>(0.1707)**** |
| Total Road Miles (k miles) | | -0.002<br>(0.0002)**** | -0.002<br>(0.0002)**** | -0.002<br>(0.0002)**** |
| Household income level | | | 0.046<br>(0.0043)**** | 0.046<br>(0.0043)**** |
| Household size | | | -0.172<br>(0.0190)**** | -0.172<br>(0.0190)**** |
| Number of Vehicles in Household | | | -0.132<br>(0.0202)**** | -0.132<br>(0.0202)**** |
| Household in Urban | | | 0.178<br>(0.0422)**** | 0.178<br>(0.0422)**** |
| Race of Driver | | | -0.067<br>(0.0586) | -0.067<br>(0.0586) |
| Age of driver | | | -0.037<br>(0.0015)**** | -0.037<br>(0.0015)**** |
| Female Driver | | | 1.081<br>(0.0382)**** | 1.081<br>(0.0382)**** |
| Education Level [a] | | | -2.306<br>(0.0970)**** | -2.306<br>(0.0970)**** |
| Less than high school | | | -2.075<br>(0.0631)**** | -2.075<br>(0.0631)**** |
| High school Graduate | | | -1.551<br>(0.0592)**** | -1.551<br>(0.0592)**** |
| Some college | | | -0.990<br>(0.0604)**** | -0.990<br>(0.0604)**** |
| College degree | | | | |

a: compared to Graduate and professional degree

Significant level: * at 0.05; **: at 0.01; ***: at 0.001; ****: < 0.0001

# Full Model Estimates (Clustered Robust SE)

| Parameter | Best Estimated Annual Miles | | | |
|---|---|---|---|---|
| Intercept | 11034.58 (177.569)** | 16200.93 (1311.776)** | 22059.47 (456.369)** | 21989.86 (456.742)** |
| Toll Road Miles% | -996.16 (523.176) | -1035.27 (402.873)* | -518.92 (149.584)* | |
| Std. Toll Road Miles% | | | | -118.73 (34.225)* |
| Price of Gasoline, regular grade | 397.06 (313.154) | 311.38 (171.779) | 158.44 (152.678) | 158.44 (152.678) |
| Total Road Miles (k miles) | | -2363.42 (583.915)** | -3229.35 (198.197)** | -3229.35 (198.197)** |
| Household income level | | 1.405 (0.6416)* | 1.376 (0.3811)** | 1.376 (0.3811)** |
| Household size | | | 182.13 (7.352)** | 182.13 (7.352)** |
| Number of Vehicles in Household | | | 536.68 (23.217)** | 536.68 (23.217)** |
| Household in Urban | | | -73.02 (26.466)* | -73.02 (26.466)* |
| Race of Driver | | | -1440.44 (85.182)** | -1440.44 (85.182)** |
| Age of driver | | | 263.35 (72.945)** | 263.35 (72.945)** |
| Female Driver | | | -93.32 (1.931)** | -93.32 (1.931)** |
| Education Level [a] | | | -769.01 (61.570)** | -769.01 (61.570)** |
| Less than high school | | | -667.38 (62.972)** | -667.38 (62.972)** |
| High school Graduate | | | -690.95 (63.829)** | -690.95 (63.829)** |
| Some college | | | -163.96 (58.520)* | -163.96 (58.520)* |
| College degree | | | -293.34 (89.107)* | -293.34 (89.107)* |

a: compared to Graduate and professional degree

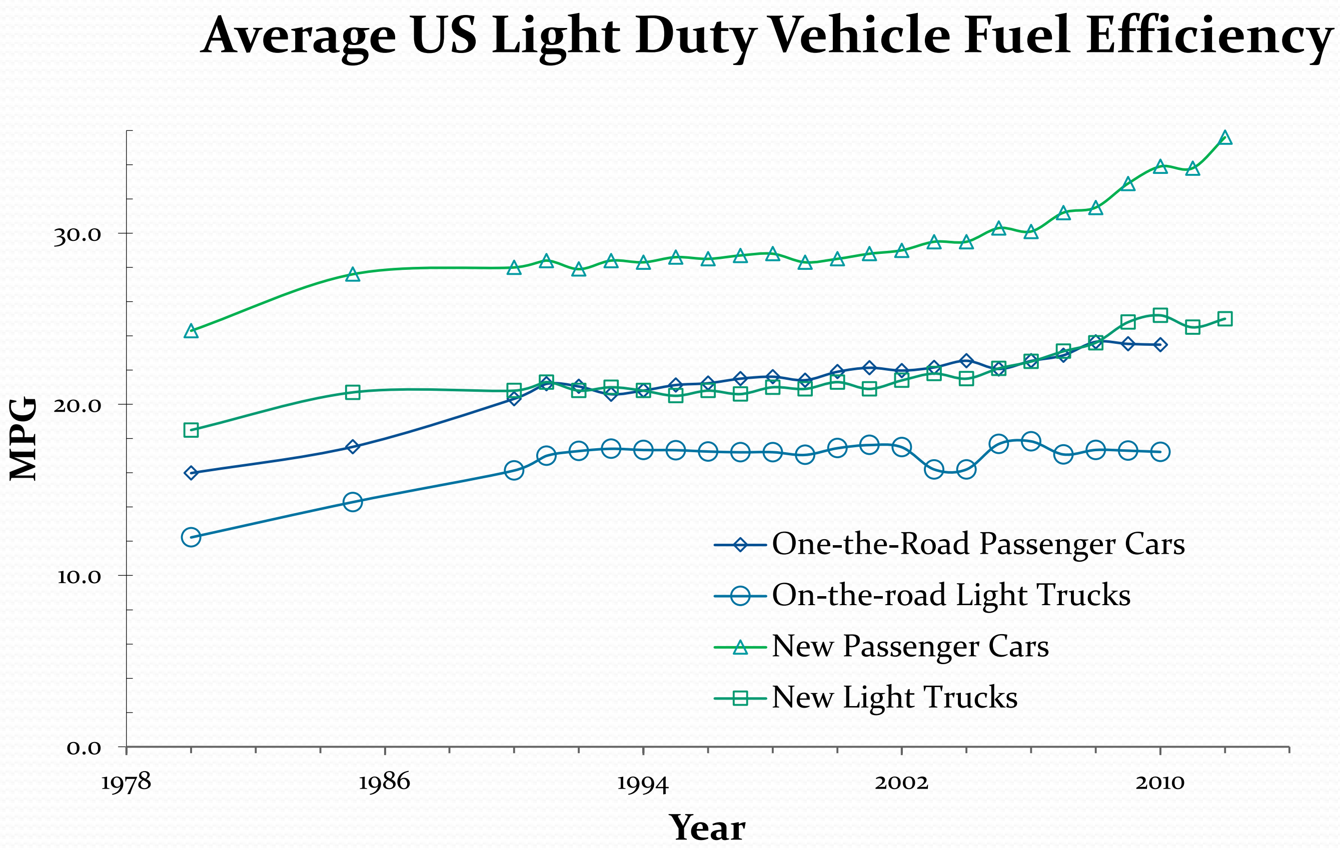
Significant level: * at 0.01 **: at <0.001.

# Full Model Estimates (Clustered Robust SE)

| Parameter | EIA Derived Gasoline-equivalent MPG | | | |
|---|---|---|---|---|
| Intercept | 21.07 (0.059)** | 12.28 (0.992)** | 17.03 (0.966)** | 17.13 (0.954)** |
| Toll Road Miles% | 0.67 (1.005) | 0.71 (0.400) | 0.75 (0.325)* | |
| Std. Toll Road Miles% | | | | 0.17 (0.074)* |
| Price of Gasoline, regular grade | 0.17 (0.368) | 0.32 (0.151)* | 0.22 (0.155) | 0.22 (0.155) |
| Total Road Miles (k miles) | | 4.04 (0.438)** | 3.28 (0.445)** | 3.28 (0.445)** |
| Household income level | | -0.003 (0.0004)** | -0.003 (0.0005)** | -0.003 (0.0005)** |
| Household size | | | 0.05 (0.006)** | 0.05 (0.006)** |
| Number of Vehicles in Household | | | -0.17 (0.029)** | -0.17 (0.029)** |
| Household in Urban | | | -0.13 (0.020)** | -0.13 (0.020)** |
| Race of Driver | | | 0.18 (0.070)* | 0.18 (0.070)* |
| Age of driver | | | -0.05 (0.082) | -0.05 (0.082) |
| Female Driver | | | -0.04 (0.002)** | -0.04 (0.002)** |
| Education Level [a] | | | 1.08 (0.083)** | 1.08 (0.083)** |
| Less than high school | | | -2.31 (0.159)** | -2.31 (0.159)** |
| High school Graduate | | | -2.07 (0.143)** | -2.07 (0.143)** |
| Some college | | | -1.55 (0.146)** | -1.55 (0.146)** |
| College degree | | | -0.99 (0.120)** | -0.99 (0.120)** |

a: compared to Graduate and professional degree
Significant level: * at 0.05; **: at 0.01; ***: at 0.001; ****: < 0.0001

# Improvements in Vehicle Fuel Efficiency




Data source: US DOT NTS

# Downfalls of CAFE standard

Due to improved vehicle fuel economy

1. Rebound effects: agents save fuel cost, however drive more, damage road more
2. Less fuel tax revenue to fund road development and maintenance