Drive Less, Drive Better, or Both? Behavioral Adjustments to Fuel Price Changes in Germany

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What is Energy Efficiency?

- Definition from Sorrell et al. (2009):

$$\varepsilon = \text{Energy Efficiency} = \frac{\text{Useful Work}}{\text{Energy Input}}$$

- Example:
  - Useful Work = "driving 15 km," energy input = 1 l. gasoline, so ε = 15 km/liter (a.k.a. fuel economy)
  - With cars, ε termed "fuel efficiency" or "fuel economy"
  - Larger ε is good
  - Most European drivers familiar with the reciprocal of ε, i.e., the fuel consumption rate, 1/15 = 0.067 liters per km or 6.7 liters per 100 km. → a small mumber is good

- If the energy input is a fossil fuel, higher ε should reduce GHG emissions.

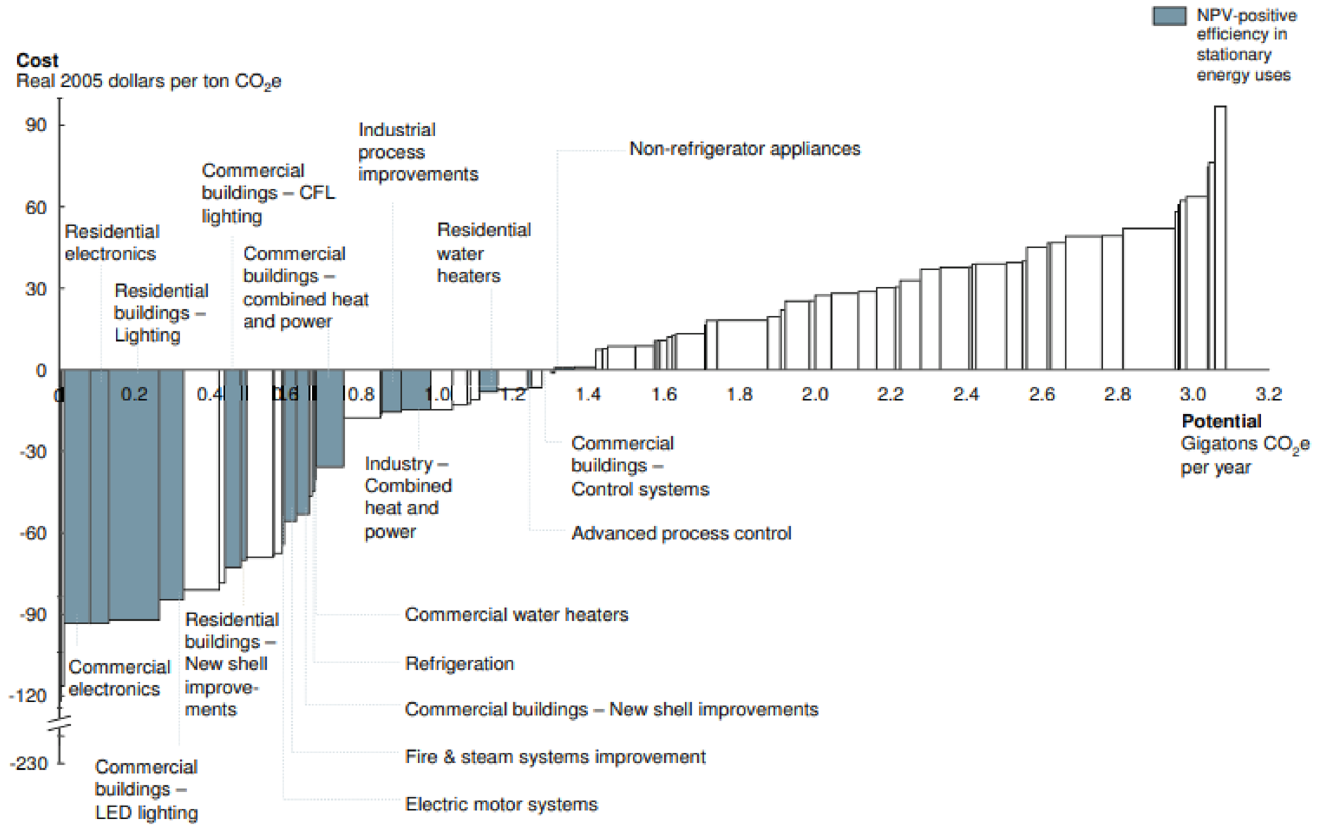
Importance of Energy Efficiency/Fuel Economy

- McKinsey report (2009)
  - Improved energy efficiency delivers GHG emissions reductions at low or negative costs
- Energy efficiency gap
- Concerns about rebound effect
- Which policies actually encourage energy efficiency/fuel economy improvements?
  - Regulations
  - Pricing
  - Incentives
- What are possible adverse effects of these policies?
  - Efficiency concerns
  - Free-riding

McKinsey Report: Cost of GHG Savings Associated with Various Energy Efficiency Opportunities

Exhibit G: U.S. mid-range greenhouse gas abatement curve – 2030

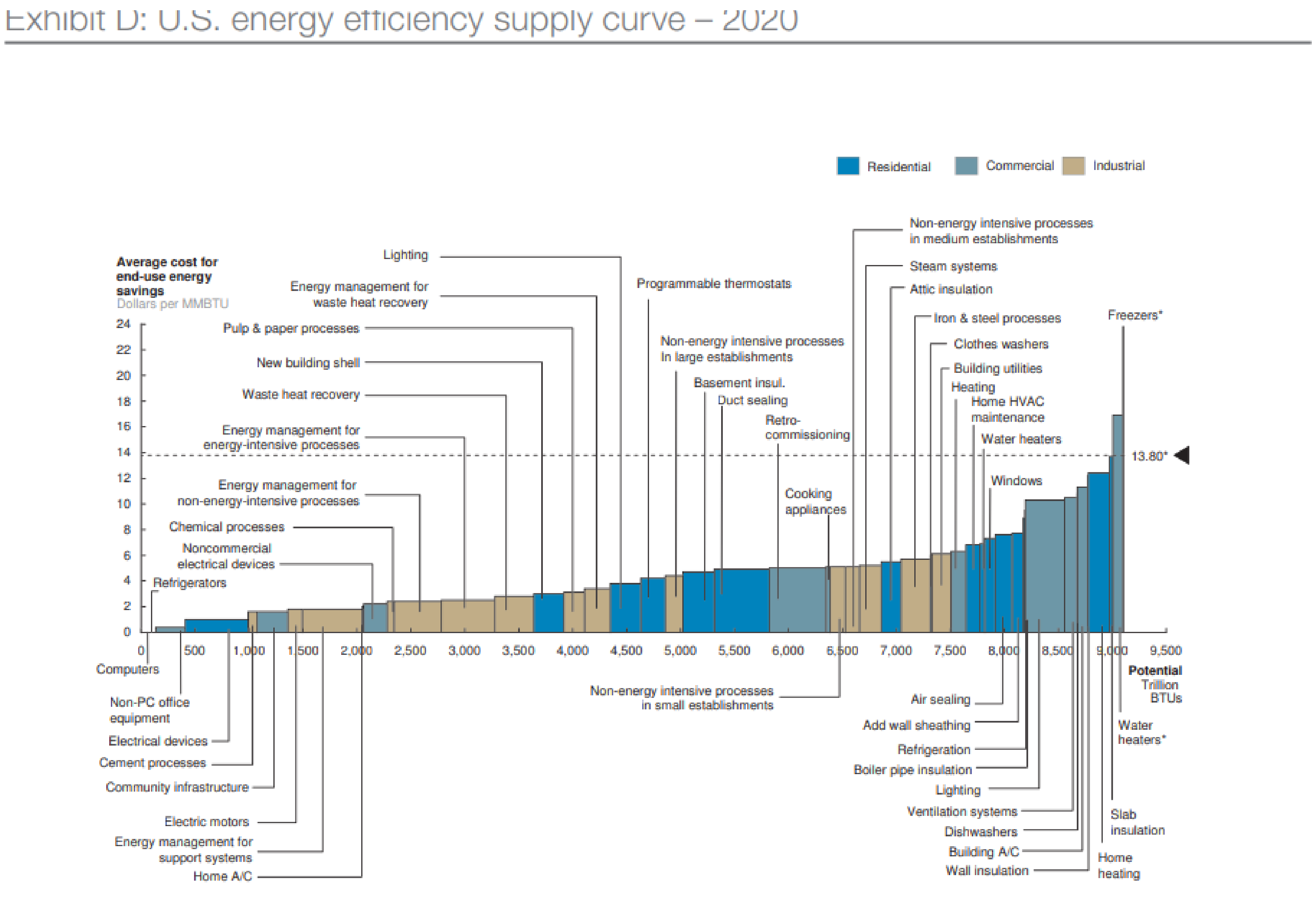
This exhibit shows greenhouse gas abatement potential as depicted in the mid-range case in McKinsey's greenhouse gas report (2007), with energy efficiency opportunities associated with stationary uses of energy highlighted. The height of each bar represents the incremental cost in dollars to abate one ton of carbon dioxide (or its equivalent); the width shows the gigatons of such emissions that could be abated per year.



Source: McKinsey analysis

McKinsey report: Energy Efficiency Supply Curve for 2020

The width of each column on the chart represents the amount of efficiency potential (in trillion BTUs) found in that group of measures, as modeled in the report. The height of each bar corresponds to the average annualized cost (in dollars per million BTUs of potential) of that group of measures.



* Average price of avoided energy consumption at the industrial price; $35.60/MMBTU represents the highest regional electricity price used; new build cost based on AEO 2008 future construction costs

Source: EIA AEO 2008, McKinsey analysis

How Does Fuel Price Affect Fuel Consumption?

$$C = \frac{Vehicle\ Km\ Traveled\ (VKT)}{Fuel\ Economy}$$

Consumption (liters of fuel)

More consumption =
More emissions

$$\frac{\partial C}{\partial p} \cdot \frac{p}{C} = \frac{\partial VKT}{\partial p} \cdot \frac{p}{VKT} - \frac{\partial FE}{\partial p} \cdot \frac{p}{FE}$$

A B C

Earlier Literature: (A)
How Does Fuel Consumption Depend on Fuel Price?

- Very large literature that goes back to the 1970s
- Price elasticity of fuel consumption very low (-0.1 to -0.2)
- Recent empirical work:
  - Variation in fuel price comes from two sources:
    - Fluctuations in tax-exclusive price over time or across places (fluctuations of world-market oil price, local demand and supply)
    - Changes in fuel taxes
- Rivers and Schaufele (2015)
  - Carbon tax first imposed in British Columbia (later extended to the rest of Canada)
  - 1% change in gasoline price caused by market forces →0.42% change in gasoline consumption
  - 1% change in gasoline price coming from a tax → 1.68% change in gasoline consumption

Earlier Literature: (B)
How Does Driving (VKT) Depend on Fuel Price?

- Large literature
- VKT not very elastic with respect to the price of gasoline
  - Greening et al. (2000) lit review: -0.09 to -0.31
- Suggestions that responsiveness to price smaller and smaller over time
- Gillingham et al. (2016)
  - Uses subsequent odometer readings from existing cars to compute annual VKT
  - Price elasticity of VKT $\approx$ -0.10 on average
  - Stronger elasticity (-0.19) among cars with poor fuel economy
  - Stronger elasticity (-0.41) among cars aged 4-7 years

Earlier Literature: (C)
How Does the Fuel Economy Depend on Fuel Price?

- Primarily w/ **new car** sales (Kilian, 2008)
- Hastings and Shapiro (2013)
  - When the price of gasoline rises, people don't buy cars with better fuel economy: They simply substitute towards lower-grade gasoline
- Langer and Miller (2013)
  - When the price of gasoline rises, manufacturers and auto dealerships offer discounts on the price of fuel-inefficient cars
- Busse et al. (2013)
  - Adjustments in the shares of fuel-efficient cars in the new car market, in the prices in the used car market
- Klier and Linn (2010)
  - New car sales in the US; (short-run) price elasticity of new car fuel economy -0.12
  - A $1 increase in gasoline price → 0.8 – 1 MPG improvement

How Does the Fuel Economy Depend on Fuel Price? (cont'd)

- Li, Timmins and Von Haefen (2009)
  - Use registration data
  - 10% increase in fuel price → 0.22% increase in fuel economy in the short run
    2.04% increase in fuel economy in the long run
  - Fuel price increases…
    - re-direct sales towards more efficient models, and
    - Accelerate scrappage
- Rivers and Schaufele (2017)
  - New cars in Canada, 2000-2010
  - A 1% increase in gasoline prices results in a 0.08% improvement in the fuel economy
  - …but the elasticity varies across components of the fuel price:
    - Tax-exclusive gasoline price 0.08
    - Gasoline tax 0.312

But what affects the fuel economy in an existing car?

- Engineering literature
  - Looks primarily at factors affecting the fuel economy
  - On-road v. type-approval testing
  - No attention to the role of fuel prices
- Fontaras et al. (2017)
  - Cargo
  - Temperature (directly on efficiency of combustion and indirectly via use of A/C and heating)
  - Aerodynamics (e.g., rack on top of the car)
  - Road conditions
  - Weather
  - Driving style
  - Eco-driving, esp. if combined with technology (stop-start, navigation, ...)- up to 30% improvements?

- Tietge et al. (2017)
  - The discrepancy between on-road fuel economy and official test fuel economy has been growing over 2001-2014
  - Official fuel economy, mass, engine size, mfg. year explain 90% of the variation in on-road fuel economy
- Greene et al. (2017)
  - 600,000+ obs. reported directly by motorists to myMPG.gov
  - Gasoline cars: 23% of total variability is within-vehicle, 77% between-vehicle
  - The most important predictor of on-road fuel economy is the EPA-certified fuel economy
  - Smaller roles of odometer reading, daily km driven on on-road fuel economy, temperature, driving style

Alberini, Horvath and Vance (2020)

- Get estimates of
  - elasticity of VKT wrt fuel price (component (B) in slide 6)
  - elasticity fuel economy wrt fuel price (component (C) in slide 6)
- Both based on actual, on-road micro-level data
- Germany Mobility Panel (GMOP)
  - Started in 1997
  - Households participate for three years, then are rotated out
  - We use 2004-2019
  - Spring survey (over 7 weeks): Household members record every (re)fueling, incl. liters of fuel bought, odometer reading, price per liter and total paid
  - Compute monthly km driven, and average fuel economy

Fuel Economy Equation

$$lnFE_{it} = const + \alpha \cdot lnFuelPrice_{it} + \beta \cdot lnOfficial\ FE_i + \gamma \cdot Age_{it} + \mathbf{x}_{it}\boldsymbol{\delta} + \mathbf{w}_{it}\boldsymbol{\lambda} + \varepsilon_{it}$$

i=individual car (our unit of observation)
t=year

We do not have the Official Fuel Economy, but we know that engine size, horsepower, fuel type, make and manuf. year explain 80% of the variation in it (Emissions Analytics, 2020)…so we plug those in:

$$lnFE_{it} = \alpha \cdot lnFuelPrice_{it} + \mathbf{z}_{it}\boldsymbol{\beta} + \mathbf{x}_{it}\boldsymbol{\delta} + \mathbf{w}_{it}\boldsymbol{\lambda} + \text{fixed effects} + \varepsilon_{it}$$

Demand for Km Driven

$$VKT = A \cdot (price\ per\ km)^b \cdot INCOME^h \cdot X^c \cdot \exp(\eta)$$

but…

$$price\ per\ km = price\ per\ liter / km\ per\ liter$$

so on taking logs and substituting:

$$\ln monthly\ km_{it} = b \cdot \ln Fuel\ Price_{it} + \mathbf{z}_{it}\boldsymbol{c} + \mathbf{x}_{it}\boldsymbol{d} + \mathbf{w}_{it}\boldsymbol{g} + \text{fixed effects} + \eta_{it}.$$

Summary of the Model

- System of 2 unrelated equations (SUR)
- Same regressors, so GLS on the SUR boils down to OLS equation by equation
- Both equations contain log fuel price
- What types of fixed effects?
  - Car fixed effects?
  - Household fixed effects?
  - Kreis-by-year fixed effects?

Heterogeneity

- Separate samples by fuel type, household type, location, etc.
- Latent class models

What’s a latent class model?

- Assumes that units (here, car or driver) belong to one of a finite number of groups or classes
- Inside a class, units share the same tastes, regression coefficients, etc.
- But different classes have different coefficients
- The problem is that we don’t know what class a unit belongs to
- …so we specify class membership probabilities, and
- The estimation routine must account for the fact that what we observe is a “weighted average” where the weights are the class membership probabilities
- A.k.a., Finite mixing distributions

Since we do not observe which class someone belongs to, we let Qc denote the class membership probability. For any one car/driver, $\sum_{c=1}^{C} Q_c = 1$. It is assumed that

(7) $$Q_{ic} = \exp(\boldsymbol{X_{ic}\tau})/\sum_{c=1}^{C} \exp(\boldsymbol{X_{ic}\tau}),$$

and, for identification, that $Q_{i1} = 1/\sum_{c=1}^{C} \exp(\boldsymbol{X_{ic}\tau})$. Denote the density of the observations on the dependent variable, conditional on belonging to class c, as $\phi\left(\frac{lnFE_{it}-m_{it,c}}{\sigma_c}\right)$ where $m_{it,c}$ denotes the right-hand side of equation (6) (excluding the error term), σ_c is the standard deviation of the error term in class c, and $\phi(.)$ is the standard normal pdf. Then the unconditional contribution of each observation to the likelihood function is

(8) $$\ell_{it} = \sum_{c=1}^{C} Q_c \cdot \phi\left(\frac{lnFE_{it}-m_{it,c}}{\sigma_c}\right),$$

and the likelihood function is $\mathcal{L} = \prod_i \prod_t \ell_{it}$.

The estimated coefficients can be used to construct posterior class membership probabilities:

$$\tilde{Q}_{ic} = \hat{Q}_{ic}\hat{\phi}_{itc}/\hat{\ell}_{it}, \tag{9}$$

where the $\hat{Q}_{ic}$, $\hat{\phi}_{itc}$ and $\hat{\ell}_{it}$ are obtained simply by plugging in the coefficient estimates into (7), (8) and (9). The predicted mean of the dependent variable for each observation is

$$\sum_{c=1}^{C} \tilde{Q}_{ic}\hat{m}_{itc} \tag{10}$$

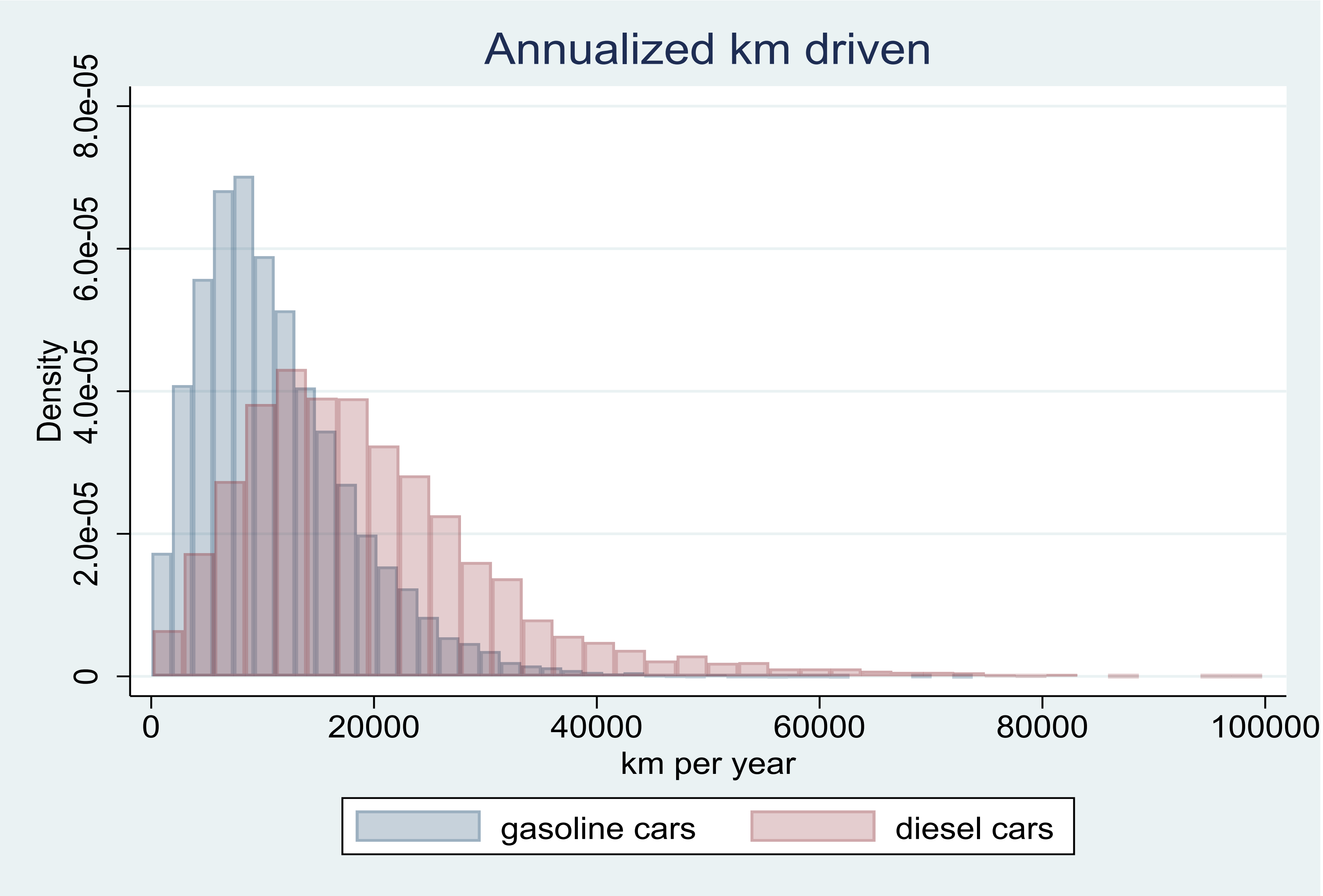
and a distribution of posterior price elasticities can be obtained as

$$\sum_{c=1}^{C} \tilde{Q}_{ic}\hat{\alpha}_{c}. \tag{11}$$

The Sample

- Number of households: 5622
- Participate in…
  - Only one wave: 37%
  - Two waves: 29%
  - Three waves: 34%
- Number of cars: 8358
  - Gasoline: 71%; Diesel: 26%
  - 6% company cars
- Households with…
  - One car: 71%
  - 2 cars: 26%
  - 3 cars: 3%
  - 4 or more cars: less than 1%
- Vehicle turnover:
  - 4.39% added each year
  - 2.25% exit, not replaced
  - 6.50% replace one or more cars, keeping total number of cars owned unchanged

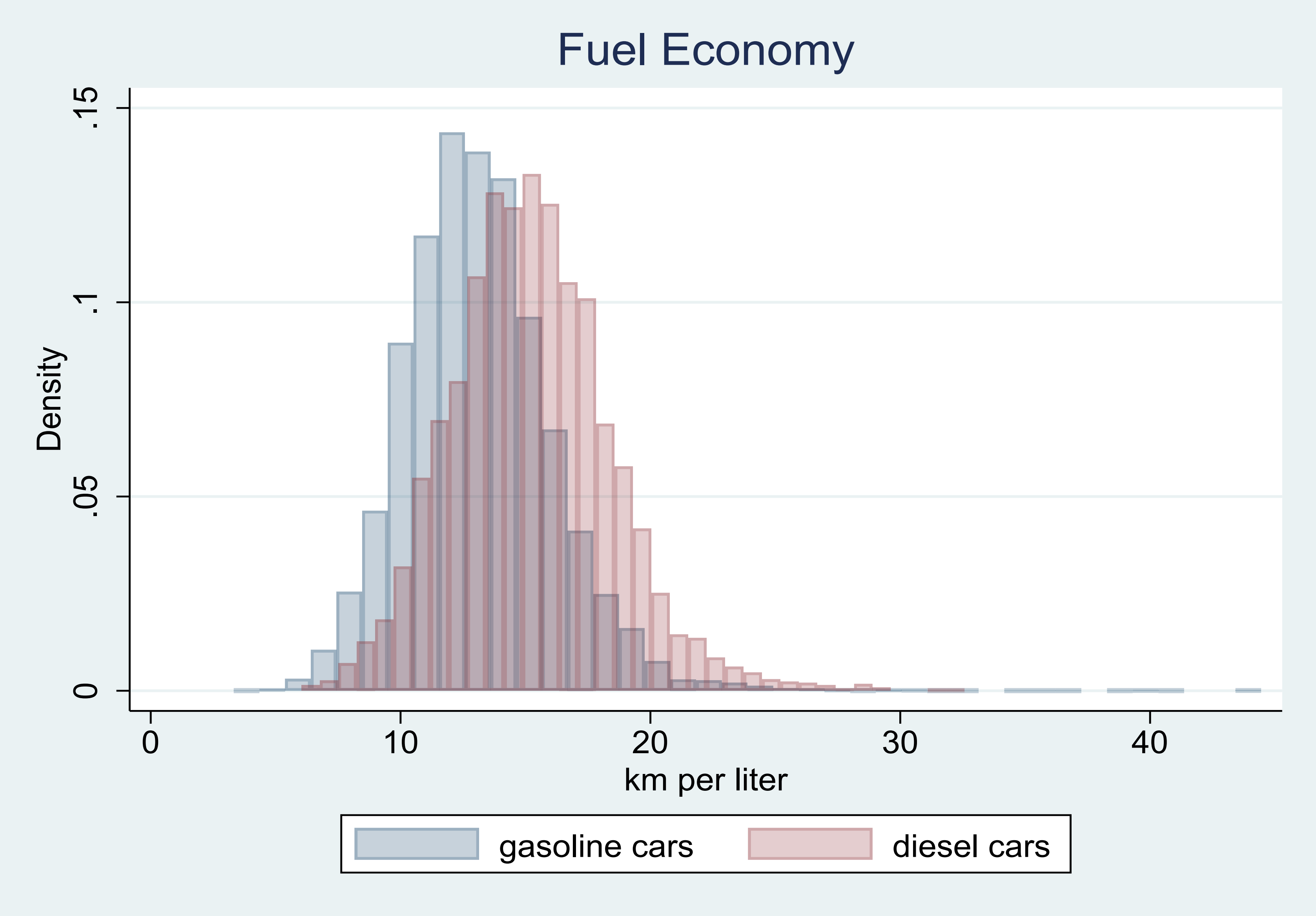
Vehicle Kilometers Traveled



Cleaned sample:

- Mean annual km: 13,159
- Mean annual km if gasoline: 11,081
- Mean annual km If diesel: 18,165

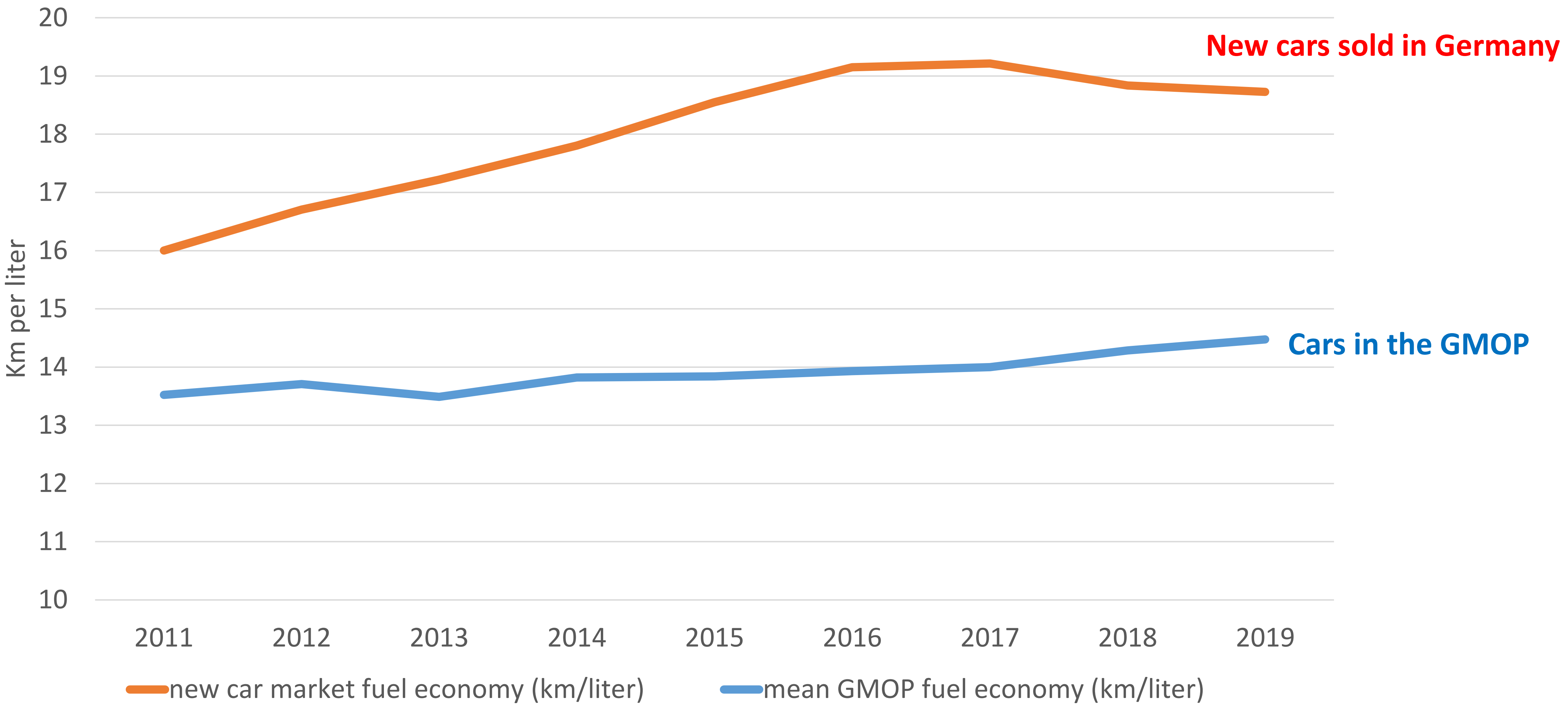
Fuel Economy



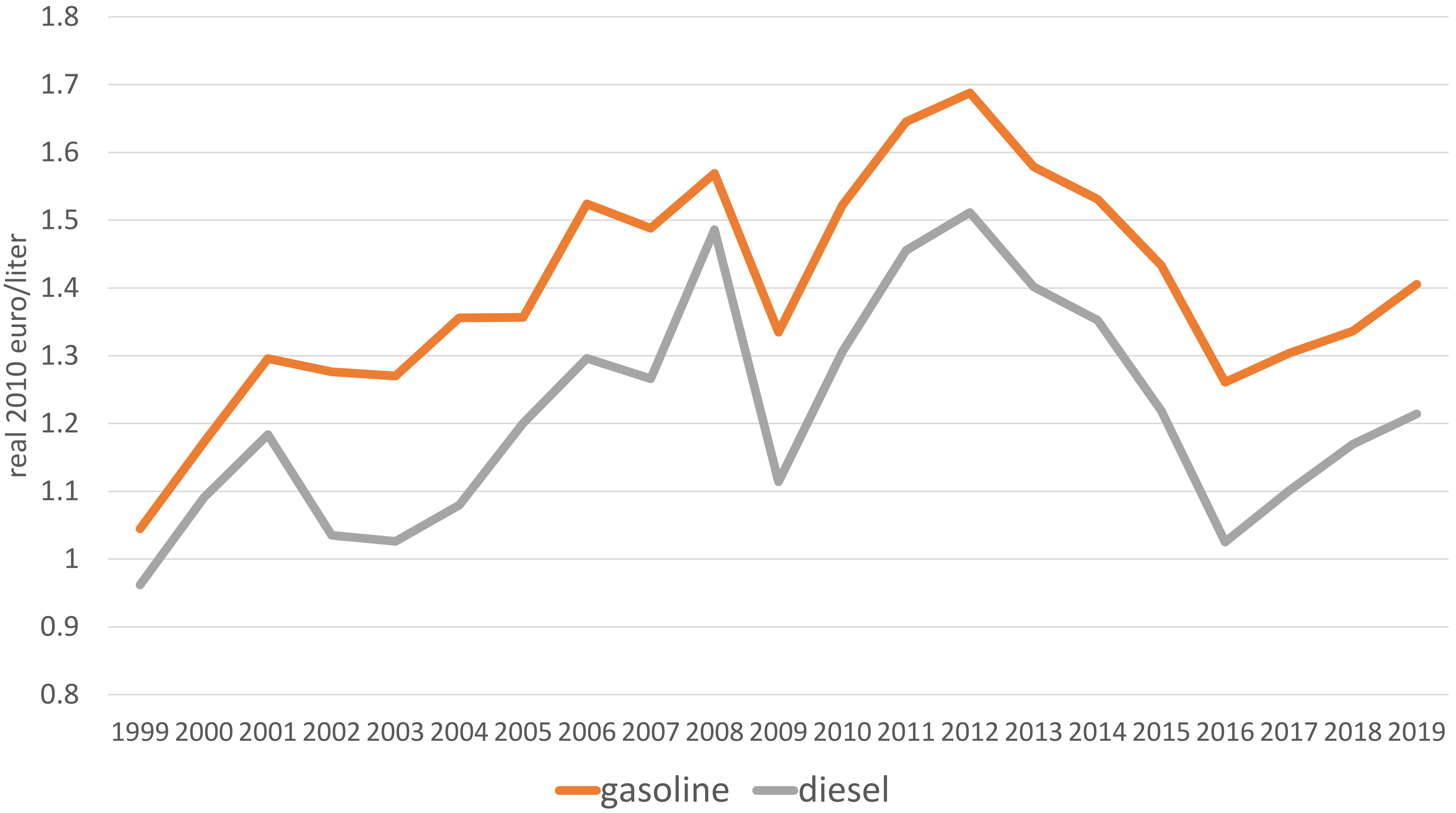
Cleaned sample:

- Mean fuel economy: 13.84 km/liter
- Mean FE if gasoline: 13.28 km/liter
- Mean FE km If diesel: 15.29 km/liter

Is the discrepancy between official and on-road fuel economy getting worse over time?



Fuel Prices



1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
real 2010 euro/liter
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
gasoline
diesel

Main Results

	(A) ln(Fuel Economy)	(B) ln(VKT)	(C) ln(Fuel Economy)	(D) ln(VKT)
ln(fuel price)	-0.076*** (0.020)	-0.252*** (0.067)	-0.023 (0.025)	-0.255*** (0.081)
ln(fuel price)×diesel car	0.058*** (0.030)	0.252** (0.099)	-0.029 (0.034)	0.326*** (0.111)
Car characteristics	Yes—important	Yes—important	Yes—important	Yes—important
Other cars owned by hh	Yes—NS	Yes—important	Yes (mixed results)	Yes—important
Household characteristics	Yes—NS	Yes—important	Yes but washed out by HH fixed effects	Yes—NS
Location	Yes	Yes	Yes	Yes
County-by-year FE Make FE Age of car FE Household FE	Yes Yes Yes No	Yes Yes Yes No	Yes Yes Yes Yes	Yes Yes Yes Yes

Gasoline v. Diesel Cars

	Gasoline cars only		Diesel cars only	
	ln(Fuel Economy)	ln(VKT)	ln(Fuel Economy)	ln(VKT)
ln(fuel price)	-0.069*** (0.021)	-0.226*** (0.072)	-0.033 (0.026)	0.074 (0.092)

Same covariates and fixed effects as before

One-car households v. the others

	One-car households		Two or more-car households	
	ln(Fuel Economy)	ln(VKT)	ln(Fuel Economy)	ln(VKT)
ln(fuel price)	-0.093*** (0.026)	-0.172* (0.089)	-0.056* (0.032)	-0.362*** (0.110)
ln(fuel price)×diesel car	0.101* (0.042)	0.053 (0.140)	0.028 (0.044)	0.472** (0.150)

Same covariates and fixed effects as before

Only household with the same cars across the waves of surveys

	ln(Fuel Economy)	ln(VKT)
ln(fuel price)	-0.089*** (0.034)	-0.256** (0.117)
ln(fuel price)×diesel car	0.131* (0.050)	0.120 (0.173)

Same covariates and fixed effects as before

Summary and Additional Checks

- Drivers of gasoline cars adjust VKT when fuel price changes in the expected ways, but their on-road fuel economy gets *worse* when the price of gasoline rises
- Drivers of diesel cars don't respond to fuel prices
- More elastic response by households with no working members
- Results are robust to…
  - Clustering standard errors are the car, or household, or kreis-by-year level
  - Rural v. urban households
  - Bottom quintile of the distribution of income v. the others
  - Top quintile of the distribution of income v. the others
  - Dropping company cars

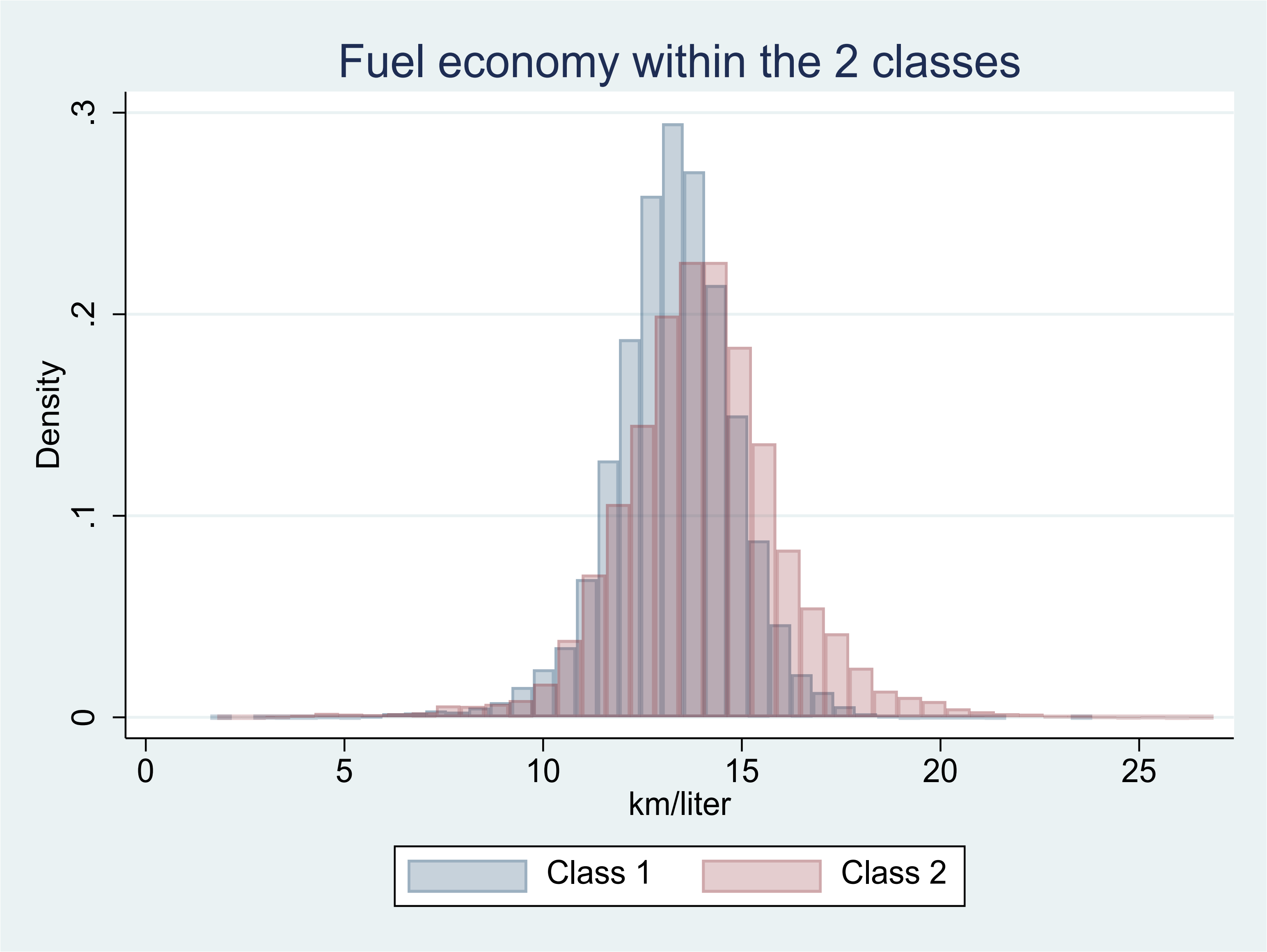
Interpretation

- Extensive v. intensive margin:
  - People who must drive a lot (and place importance on the fuel economy) buy diesel car
  - Once they have their diesel cars, they don't respond to fluctuations in diesel prices
- Gasoline car drivers adjust their VKT to changing prices.
- **Why** does their fuel economy get worse as fuel price increases? Perhaps they…
  - Give up long drives where they would drive at regular, optimal speeds
  - Drive more of their km in the city
  - Share their car with other household members more → heavier "cargo," worse fuel economy
- The same behaviors that reduce km driven (and hence fuel consumed, and emissions) worsen the fuel economy (and partly offset the fuel and emissions saved)?

Latent class model results

- Only 2 classes
- Fuel economy model:
  - Only one variable associated with class membership probabilities (prob. of class 2)
  - In class 1, negative price elasticity of fuel economy for gasoline cars (zero for diesel)
  - In class 2 (slightly more likely to contain working households), fuel economy does not respond to fuel price
- VKT model:
  - More covariates associated with prob. of class 2
  - But both classes respond in the same way to fuel prices (gasoline v. diesel)

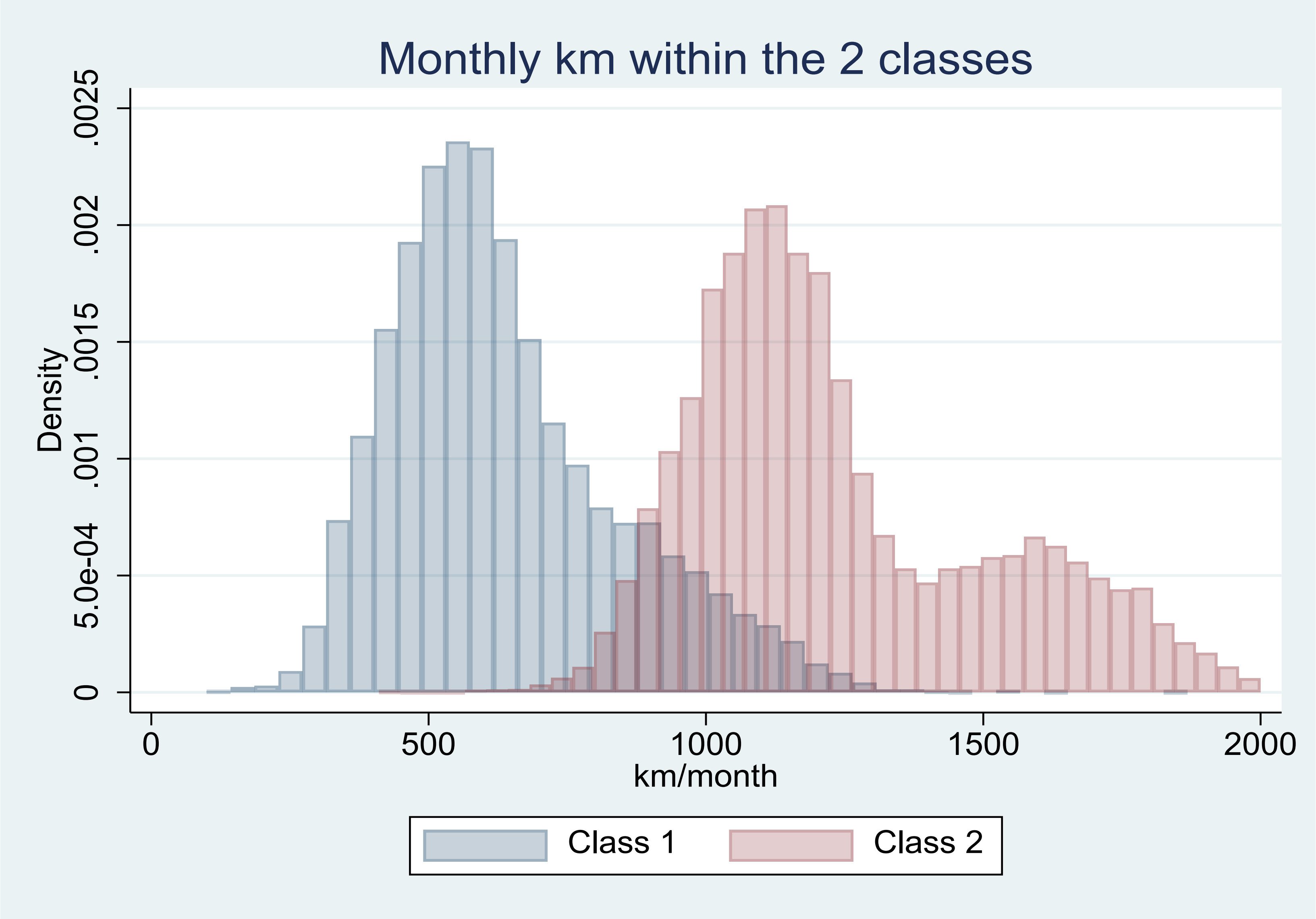
Fuel economy predicted by the latent class model



Class 2 is the one whose fuel economy is predicted to be insensitive to fuel price, for both gasoline and diesel cars.

But assignment to class 1 or 2 is very iffy.

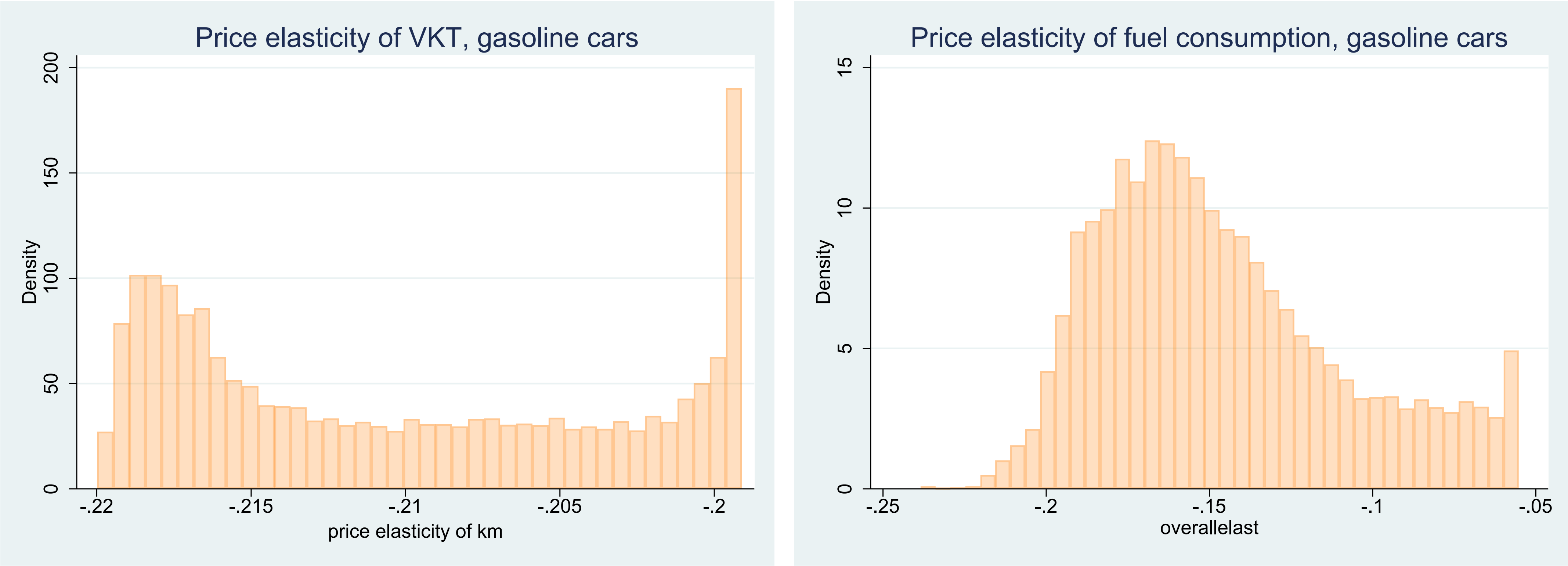
VKT predicted by the latent class model



Class 2 likely to contain people from working households, with children, mid- to high income.

But the responsiveness to fuel prices is the same in both classes.

Posterior distributions of the elasticities (gasoline cars)



Very narrow range for the price elasticity of VKT. The price elasticity of fuel consumption is more variable because we must subtract the price elasticity of the fuel economy.

Policy implications

- Short-term response to fuel prices observed among those that did not already self-select into more fuel-efficient cars
- Even for these drivers, the effect on total fuel consumption is eroded by the “adverse” response of the fuel economy to fuel price changes
  - Gasoline cars
  - VKT price elasticity ≈-0.25, minus fuel economy price elasticity ≈-0.07, equals ≈-0.18 overall consumption price elasticity
- What would a carbon tax do?
  - 25 euro/ton CO_2 → increase price by 5.75 eurocents/liter → reduce CO_2 emissions by 592,205 tons/year (less than 1% of emissions from passenger cars)
  - 55 euro/ton CO_2→ reduce CO_2 emissions by 1,303,000 tons/year (1.35%)
  - but if the responsiveness to a fuel tax is truly stronger than that for “normal” price changes, the % reductions could be 1.55% and 2.46%, resp.
- Transition to electric cars will take a while (plus, not all electricity is carbon-free)

Conclusions

- Energy efficiency/fuel economy the "weakest link" when seeking to reduce consumption of fossil fuels via pricing?
  - Adverse effects of energy input prices observed with existing cars in this study
  - Fuel prices have very small effects on new car purchases
  - Other energy-using durables are even less susceptible (e.g., refrigerators)
- Are people locked into the energy efficiency/fuel economy decisions they made at the time they purchased new energy-using durables?
- Should more policy efforts and resources be dedicated to accelerating the replacement of energy-using durables?
  - Or will that simply trigger free-riding behaviors?
- What exactly were the causes of the "adverse" relationship between fuel prices and the on-road fuel economy here?

Thank you!
Comments?
Questions?
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