

Consumer Satisfaction with New Vehicles Subject to Greenhouse Gas and Fuel Economy Standards

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Are there hidden costs as a result of adoption of fuel-saving technologies?

- A variety of fuel-saving technologies have been implemented since model year 2012 under the EPA light-duty vehicle greenhouse gas emissions standards
- Questions have been raised about whether there are hidden costs
 - E.g., Allcott and Greenstone (2012), Gillingham and Palmer (2014)
 - If hidden costs exist, they might contribute to an explanation of the existence of the energy-efficiency gap in the light-duty vehicle market
- Hidden costs are undesirable impacts of vehicle operational characteristics (Helfand et al. 2016), including:
 - Drivability: Acceleration, handling, ride comfort
 - Noise, vibration, fuel economy

Previous work did not find systematic evidence of hidden costs associated with fuel-saving technology

- Empirical challenge: Operational characteristics are not easy to measure and quantify
- Helfand et al. (2016) and Huang et al. (2017):
 - Using content analysis of online professional auto reviews for model years 2014 and 2015 vehicles
 - However, professional auto reviewers may not reflect the true experience of vehicle consumers
- This study aims to fill this gap by using recent consumer survey data for vehicles

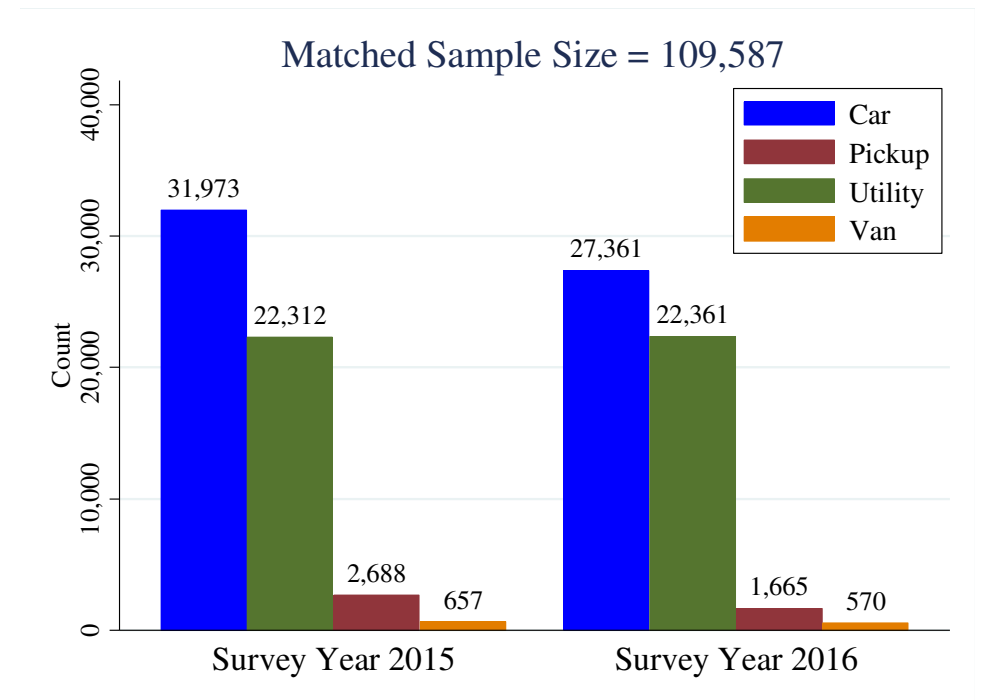
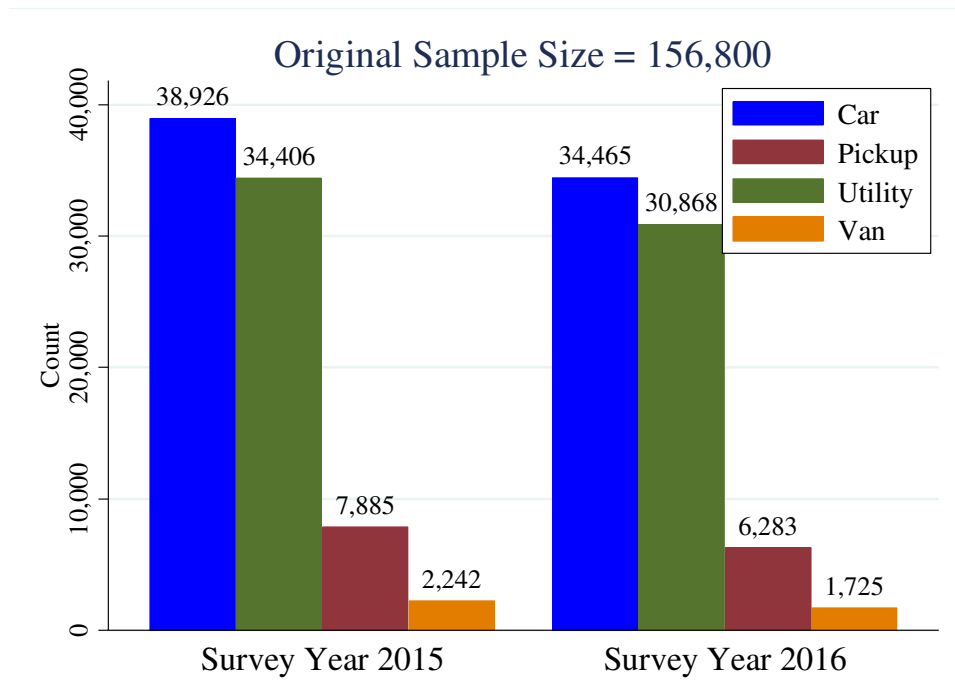
Consumer satisfaction survey data for vehicles from Strategic Version (SV)

- Stratified random sampling by SV
 - On a model (and trim) level to ensure healthy sample sizes for each model
- Consumer satisfaction rating
 - Respondents rate their experience with the vehicle and satisfaction with a comprehensive list of vehicle attributes, including operational characteristics, after they own their vehicle for 90-120 days
- Socio-demographics
 - E.g., household income, education, gender, age, residence
- Vehicle information
 - Vehicle model, engine displacement and type, number of cylinders, drive type, body type, fuel type, and transmission type

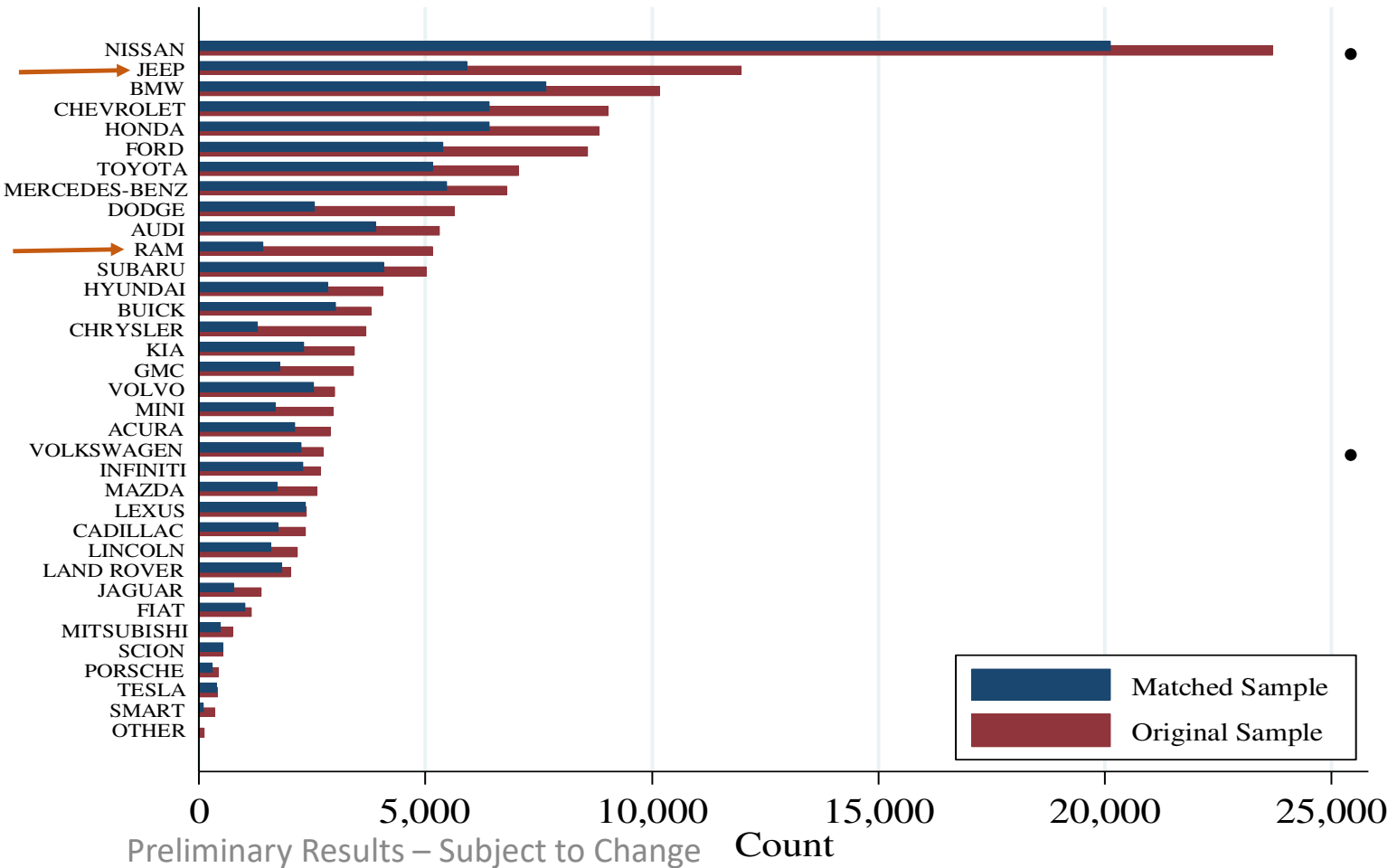
We match SV's data with detailed vehicle technology data

- Vehicle information SV provides is used to match SV survey data with more detailed technology data, which includes a variety of fuel-saving technologies
- These vehicle technology data are collected from several sources, including Edmunds, WardsAuto, fueleconomy.gov
- Currently, about 30 % of observations in the original SV data are not able to be matched with the technology data
 - We are working with SV to improve our matching ability
- So, results presented here are a proof of concept rather than final results

Matched sample is a subsample of the original sample, but the match is relatively worse for SUVs, pickups and vans



Both original sample and matched sample do not reflect sales in the population and subpopulation, respectively



- We lost many observations of pickup (e.g., Ram) and SUV (e.g., Jeep) after we matched technology data with the original SV sample
- We apply a weighting scheme to reflect sales in the subpopulation in the following analysis

Simplifying the rating scale of consumer satisfaction

- Rating scale in the survey data for survey years 2015, 2016

| | | | | | | |
|------------------|------------------|-----------------------|---------------------|------------------|-------------------|------------------|
| I Hate It | A Failure | Unsatisfactory | Satisfactory | Excellent | Delightful | I Love It |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

- We rescale the seven-scale to an indicator variable equal to:
 - 0 (=Satisfactory) if consumer's rating is 4, 5 , 6, or 7
 - 1 (=Unsatisfactory) if consumer's rating is 1, 2, or 3

Percentage of dissatisfaction with overall experience and operational characteristics

| Experience/Operational Characteristics | Original Sample | | | | Matched Sample | | | |
|--|------------------|-------------|------------------|-------------|------------------|-------------|------------------|-------------|
| | Survey Year 2015 | | Survey Year 2016 | | Survey Year 2015 | | Survey Year 2016 | |
| | Car | Light Truck | Car | Light Truck | Car | Light Truck | Car | Light Truck |
| Overall Experience | 2.5 | 2.2 | 2.2 | 2.8 | 2.5 | 2.2 | 2.3 | 2.4 |
| Overall Driving Performance | 1.4 | 1.1 | 1.4 | 1.5 | 1.5 | 1.1 | 1.5 | 1.4 |
| Ground Clearance | 3.5 | 1.3 | 4 | 1.5 | 3.4 | 1.2 | 4.3 | 1.3 |
| Riding Comfort | 2.5 | 1.6 | 2.4 | 1.9 | 2.5 | 1.8 | 2.4 | 1.8 |
| Maneuverability | 0.9 | 1 | 1.1 | 1.2 | 0.9 | 0.9 | 1.2 | 1 |
| Turning Radius | 1.3 | 1.9 | 1.3 | 2.1 | 1.4 | 1.5 | 1.2 | 1.5 |
| Road Holding Ability | 1.3 | 1 | 1.4 | 1.1 | 1.2 | 1 | 1.5 | 0.9 |
| Handling | 1.2 | 0.9 | 1.2 | 1 | 1.1 | 0.9 | 1.3 | 0.9 |
| Steering Feedback | 1.3 | 1.3 | 1.4 | 1.3 | 1.3 | 1.3 | 1.5 | 1.2 |
| Overall Power and Pickup | 3.9 | 2.7 | 3.6 | 3.3 | 4 | 3 | 3.7 | 3.3 |
| Acceleration from Stop | 4.7 | 3.4 | 4.6 | 4.2 | 4.9 | 3.6 | 4.8 | 4.2 |
| Passing Capability | 3.2 | 2.3 | 2.9 | 2.7 | 3.3 | 2.7 | 3.1 | 2.8 |
| Engine Performance | 2.5 | 2.1 | 2.5 | 2.6 | 2.5 | 2.3 | 2.6 | 2.5 |
| Overall Noise/Vibration/Harshness | 5 | 4.5 | 4.8 | 4.4 | 5.1 | 4.9 | 4.8 | 4.5 |
| Overall Quietness | 5.6 | 4.8 | 5.3 | 4.8 | 5.6 | 5.3 | 5.3 | 5 |
| Freedom from Squeaks/Rattles | 4.6 | 4.4 | 4.2 | 4.5 | 4.7 | 4.3 | 4.3 | 4.3 |
| Freedom from Wind and Road Noise | 6.9 | 5.5 | 7.1 | 6.5 | 6.9 | 6 | 7.1 | 6.7 |
| Smoothness of Vehicle at Idle | 2.4 | 2.1 | 2.2 | 2.2 | 2.5 | 2.3 | 2.2 | 2 |
| Smoothness of Transmission | 4 | 4.1 | 3.7 | 4.9 | 4.2 | 3.5 | 3.8 | 4.1 |
| Fuel Economy/Mileage | 4.9 | 10 | 4.2 | 9.5 | 4.9 | 9.7 | 4.4 | 8.9 |

Preliminary Results –
Subject to Change

Overall, vehicle owners are highly satisfied with their vehicle

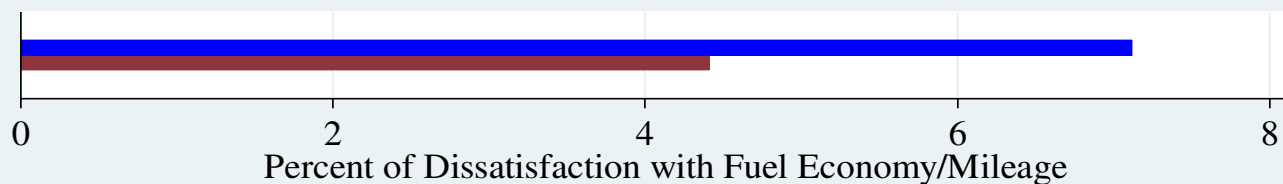
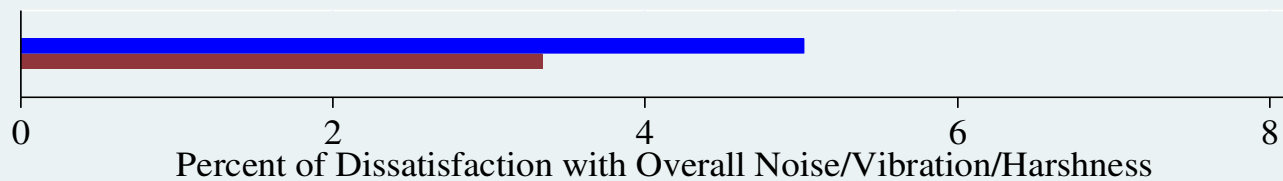
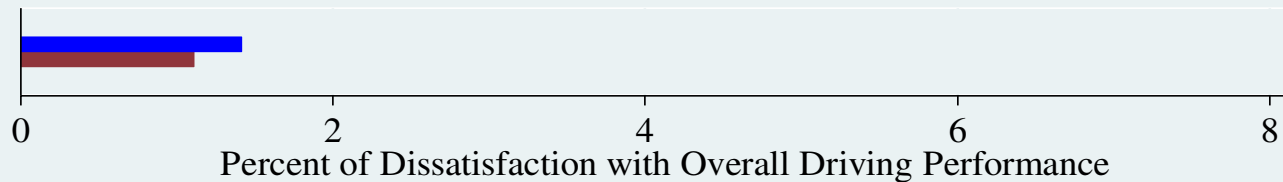
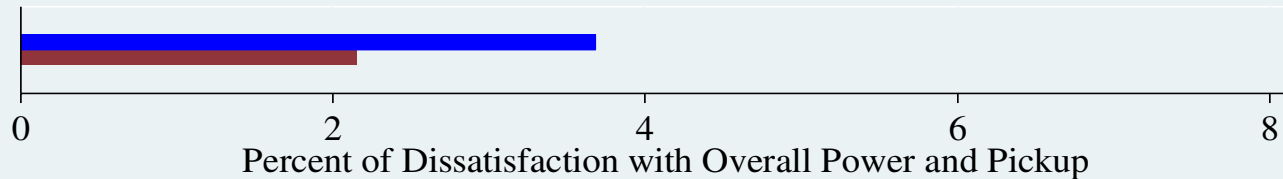
- Unsatisfactory rates using original and matched samples are similar
- Unsatisfactory rates of 2015 and 2016 are similar
- For most of operational characteristics, less than 3% of either car or light truck owners gave an unsatisfactory rating
- Unsatisfactory rates of noise and vibration are higher but below 8%
- Light truck owners have significantly higher unsatisfactory rates regarding fuel economy than car owners
- Using matched sample, this preliminary analysis focuses on overall experience and four operational characteristics:
 - Overall driving performance
 - Overall power and pickup
 - Overall/noise/vibration/harshness
 - Fuel economy/mileage

Percentage of adoption of fuel-saving technology in the matched sample is roughly similar to actual adoption share

| Fuel Saving Technology | Matched Sample | | | EPA's Fuel Economy Trends Report | |
|---|------------------|------------------|----------|----------------------------------|-----------------|
| | Survey Year 2015 | Survey Year 2016 | Combined | Model Year 2015 | Model Year 2016 |
| Continuously Variable Transmission (CVT) | 24.2 | 23.9 | 24 | 23.7 | 22.8 |
| Cooled Exhaust Gas Recirculation (Cooled EGR) | 8.5 | 7.9 | 8.3 | - | - |
| Cylinder Deactivation | 6 | 7.5 | 6.8 | 10.6 | 10.5 |
| Dual Clutch Transmission (DCT) | 2 | 2.3 | 2.2 | > 1.4 | > 2.6 |
| Diesel | 1.2 | 0.6 | 0.9 | 0.9 | 0.5 |
| Electric Vehicle (EV) | 0.7 | 0.7 | 0.7 | 0.5 | 0.5 |
| Hybrid Electric Vehicle (HEV) | 3.1 | 2.7 | 2.9 | 2.4 | 1.8 |
| High Gear Transmission (>=7) | 17.5 | 20.5 | 19 | 16.1 | 18.3 |
| Plug-in Hybrid Electric Vehicle (PHEV) | 0.4 | 0.4 | 0.4 | 0.3 | 0.3 |
| Stop-Start | 10.1 | 11.9 | 10.9 | 5.6 | 10.4 |
| Turbocharged | 14.8 | 20.2 | 17.4 | 12.6 | 15.2 |
| Variable Valve Lift | 21.8 | 19.8 | 20.9 | - | - |
| Variable Valve Timing | 97.6 | 98.4 | 98 | 96.7 | 96.9 |

Preliminary Results – Subject to Change

If there are hidden costs associated with fuel saving technology, vehicle owners would not be satisfied with vehicle operational characteristics

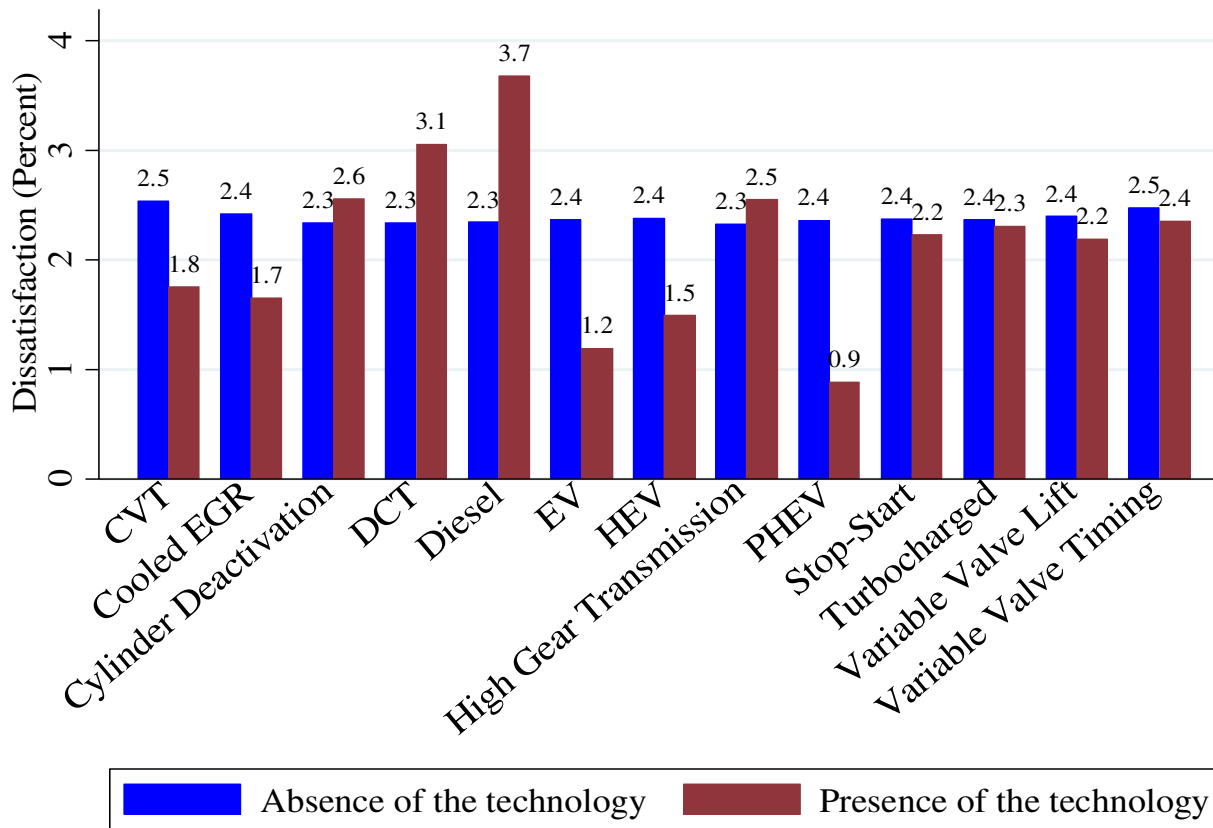


- Even vehicle owners may not know whether some technologies are in their vehicle. For example, we found some owners mistakenly report there is stop-start in their vehicle
- A simple comparison of dissatisfaction with operational characteristics over the presence of stop-start suggests hidden costs associated with stop-start may not exist

Preliminary Results
– Subject to Change



A simple comparison without controlling for any factors related to technology adoption and dissatisfaction with overall experience



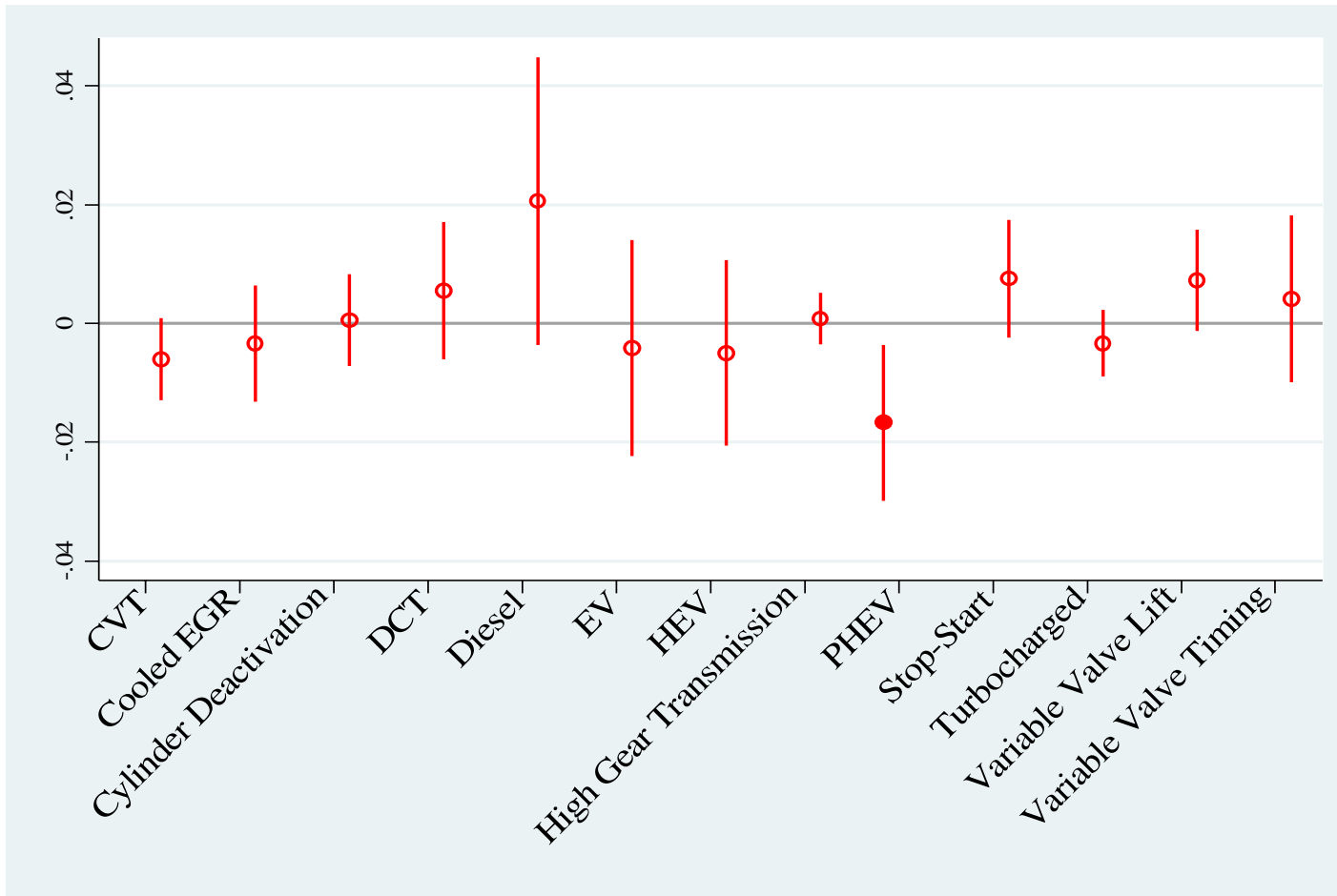
- Only very small percentage of vehicle owners is not satisfied
- It appears that percentage of dissatisfaction decreases substantially in the presence of CVT, EV, HEV, and PHEV
 - Dissatisfaction increases for DCT and diesel
- The relationship between dissatisfaction and fuel-saving technology cannot be identified without controlling for confounding factors

Linear probability regression model to explore the relationship between dissatisfaction and fuel-saving technology adopted

$$P(D_{i,j,t}^{Dissatisfactid}) = \sum_{kd} \beta_{kd} 1(FuelSavingTech_{i,k,t}) + FixedEffects + \epsilon_{i,j,t}$$

- i : respondent; t : model year; j : characteristic; k : technology
- $D_{i,j,t}^{Dissatisfactid} = 1$ if the respondent is not satisfied with the operational characteristic j , otherwise 0
- $FuelSavingTech = 1$ if the fuel-saving technology k is adopted in the vehicle, otherwise 0
- $FixedEffects$ include vehicle class, drive type, brand, model-year, household income level, gender, education, and residence fixed effects
 - For example, brand fixed effects can account for the variation of dissatisfaction caused by the time-invariant heterogeneity in the quality of technology implementation among brands

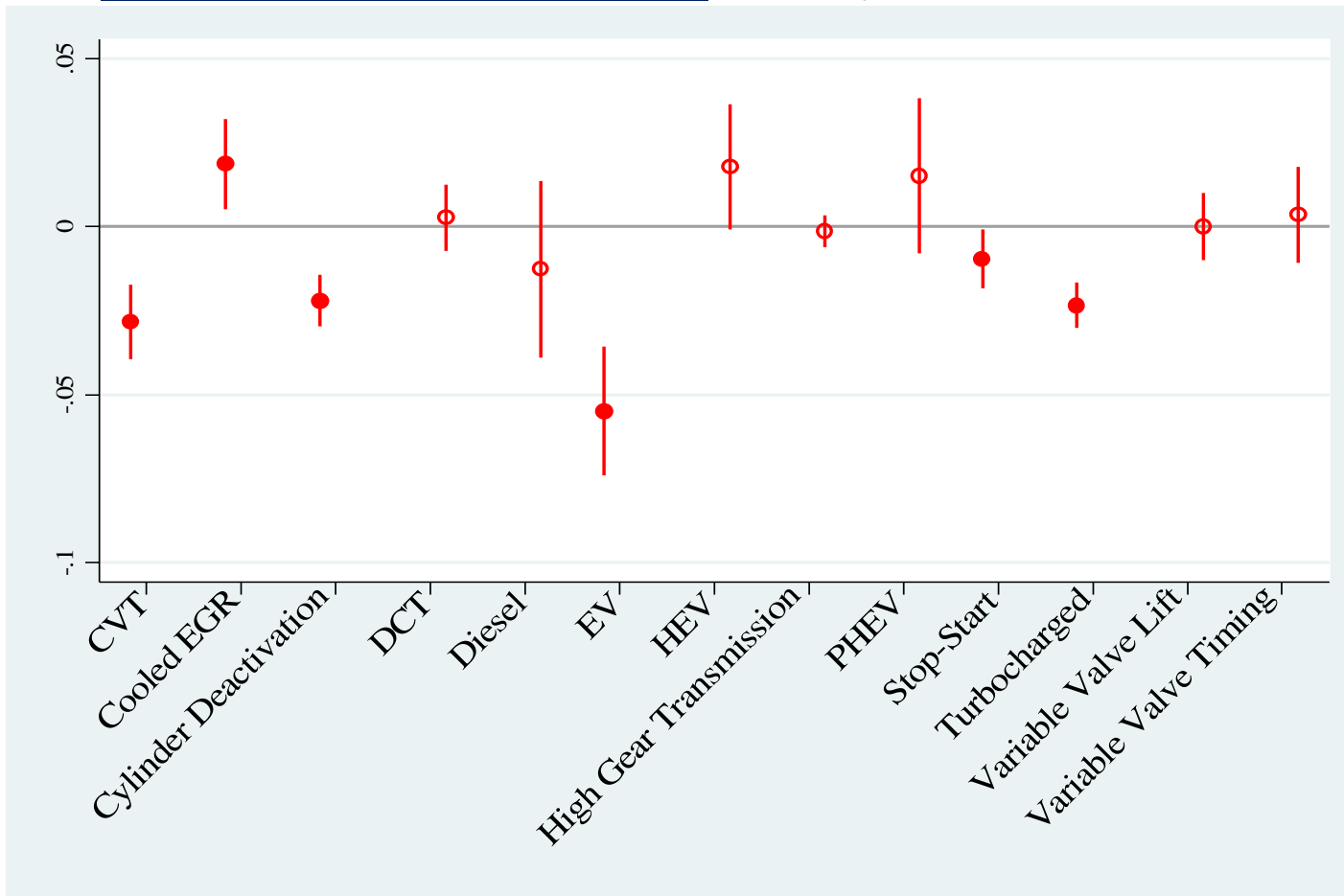
Estimated change in the probability of getting unsatisfactory rating of overall experience in the presence of a fuel-saving technology



- Estimated coefficients (with standard errors) are very small
- Negative coefficients suggest the presence of the technologies is associated with less probability of dissatisfaction
- Only the coefficient of PHEV is statistically significant at .05 significance level (with solid marker)

Preliminary Results – Subject to Change

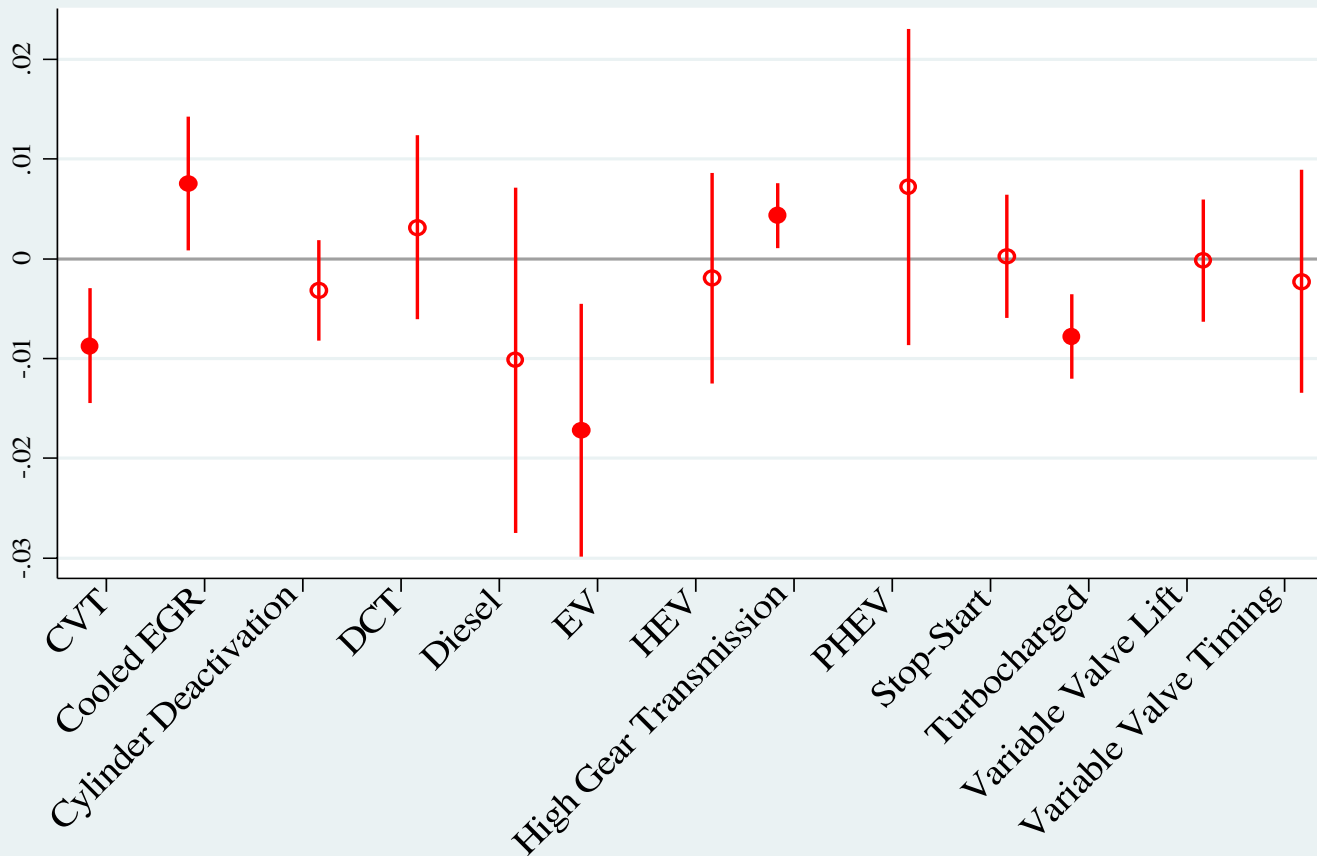
Estimated change in the probability of getting unsatisfactory rating of overall power and pickup in the presence of a fuel-saving technology



Preliminary Results – Subject to Change

- Estimated coefficients are all pretty small
- CVT, cylinder deactivation, EV, stop-start, turbocharged are correlated with less probability of dissatisfaction
- Cooled EGR is correlated with higher probability of dissatisfaction

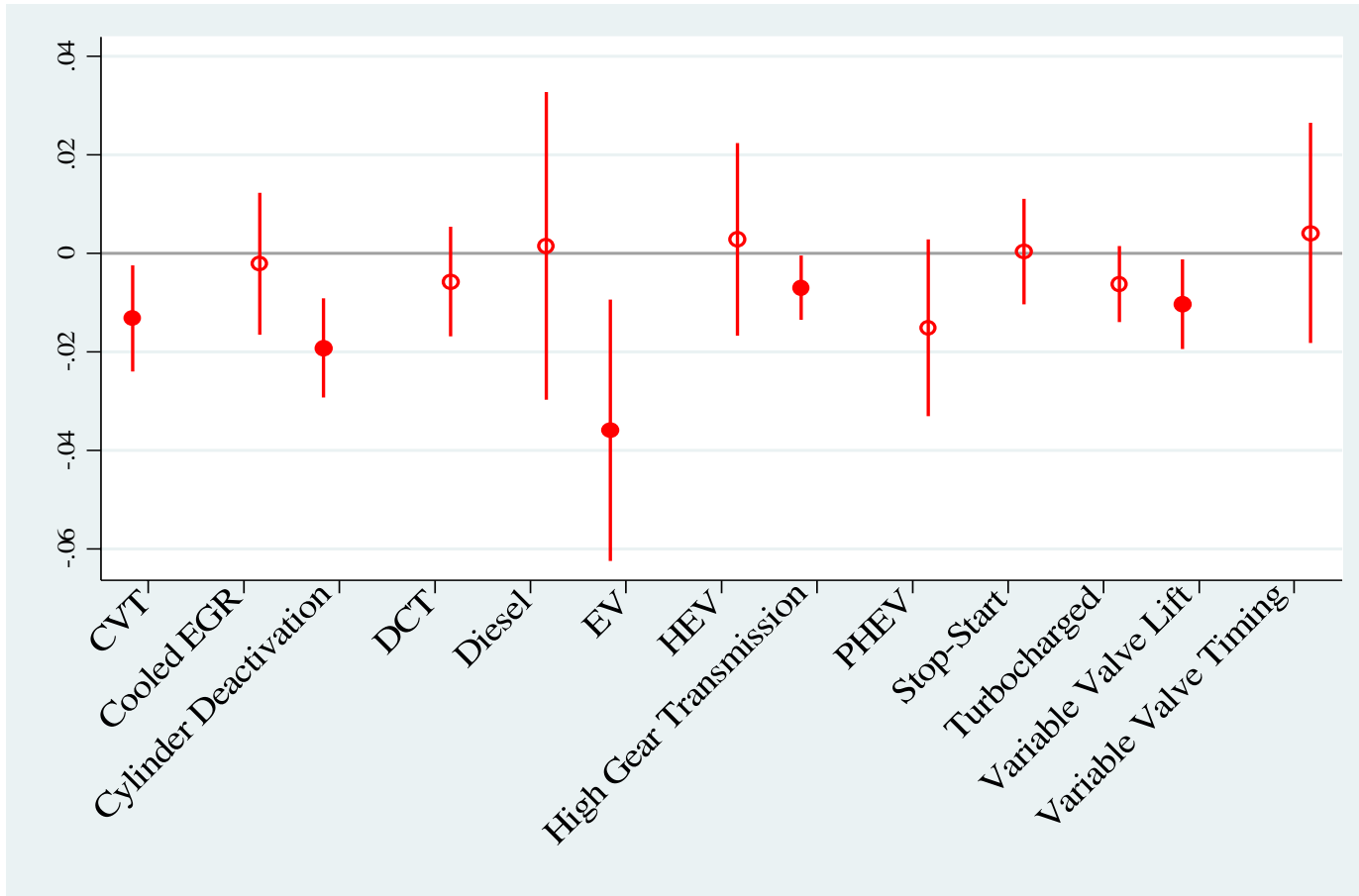
Estimated change in the probability of getting unsatisfactory rating of overall driving performance in the presence of a fuel-saving technology



- Estimated coefficients are all very small
- CVT, EV, and turbocharged are correlated with less probability of dissatisfaction
- High gear transmission and cooled EGR are correlated with higher probability of dissatisfaction

Preliminary Results – Subject to Change

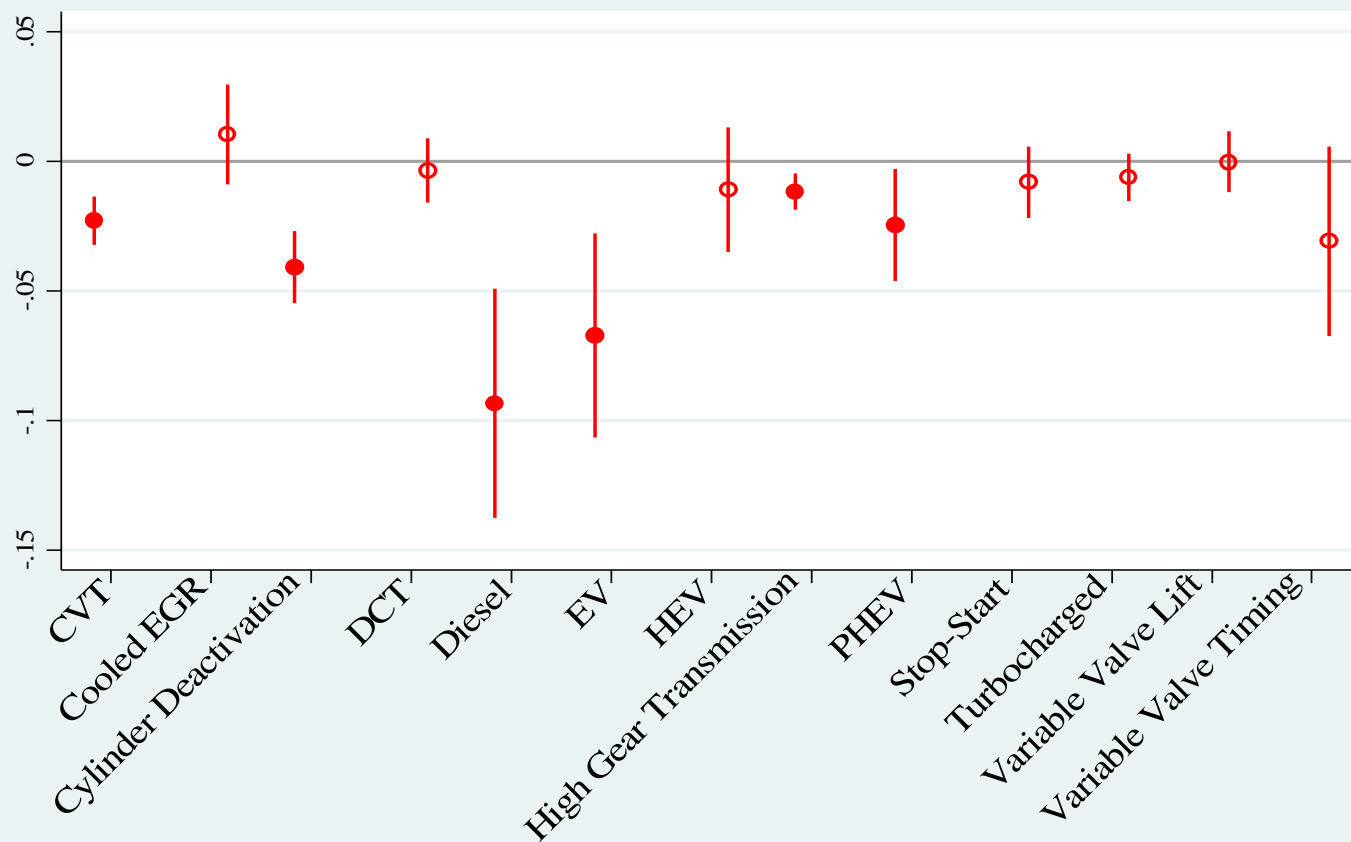
Estimated change in the probability of getting unsatisfactory rating of overall noise/vibration/harshness in the presence of a fuel-saving technology



- Estimated coefficients are all very small
- Comparing to simple graphical comparison, after controlling for the fixed effects and socio-demographics, CVT is actually correlated with less probability of dissatisfaction with overall noise/vibration/harshness

Preliminary Results – Subject to Change

Estimated change in the probability of getting unsatisfactory rating of overall fuel economy/mileage in the presence of a fuel-saving technology



- Many technologies examined are correlated with less probability of dissatisfaction
- CVT and EV show statistically-significant relationships with less probability of dissatisfaction with all the four operational characteristics

Preliminary Results – Subject to Change

Limitations

- Current matched sample does not represent the population of vehicles sold in the market
- We do not identify causal relationship
 - Observations selected to our current matched sample may be subject to selection bias
 - We cannot distinguish between technologies causing problems, or technologies being put into vehicles with problems unrelated to fuel-saving technologies
- The analysis will not capture longer-term issues, such as reliability
 - Those issues won't be known for some time, as survey questions are for buyers about their satisfaction with the new vehicles they have recently purchased
- We are working on updating the data to increase the matched sample size

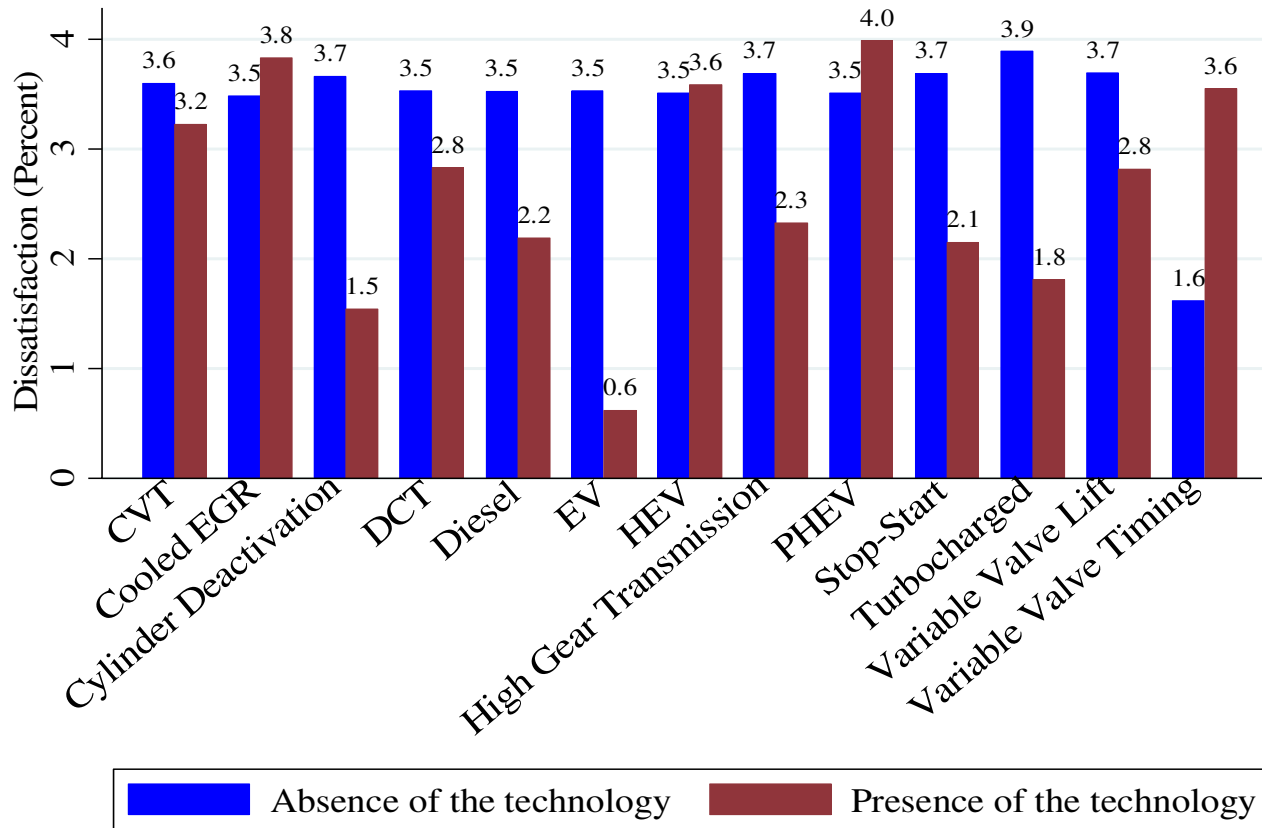
Summary of preliminary results

- Overall, vehicle consumers are highly satisfied with operational characteristics of their vehicle
- Preliminary results suggest that consumer dissatisfaction appears not correlated with fuel-saving technologies adopted in most cases
 - The coefficients are pretty small, regardless of whether they are statistically-significant or not
 - Consistent with the findings of Helfand et al. (2016) and Huang et al. (2017) using data from professional auto reviewers
 - It is important to control for observed and unobserved characteristics, such as socio-demographics and brand fixed effects

Appendix

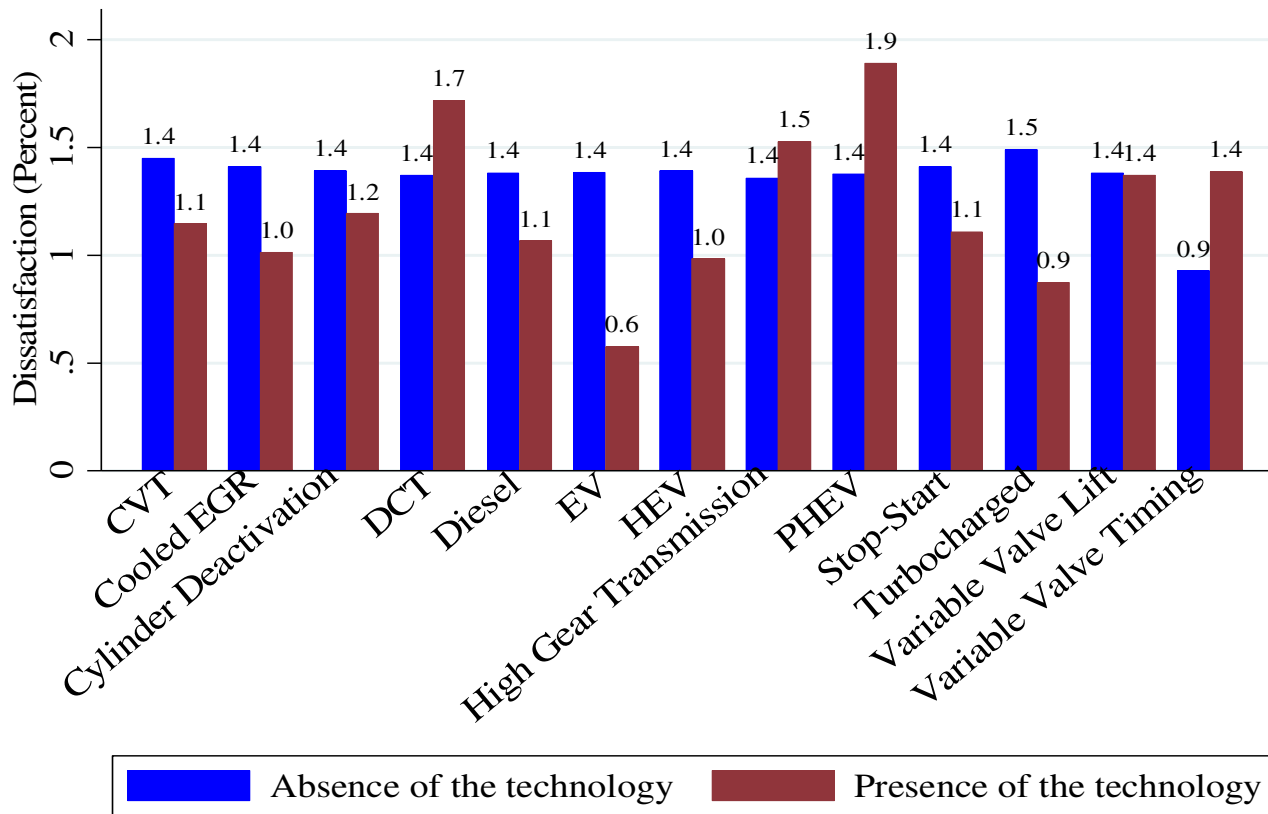
Summary statistics of dissatisfaction with operational characteristics over fuel-saving technology and its presence

Percent of dissatisfaction with overall power and pickup in the presence or absence of fuel-saving technology



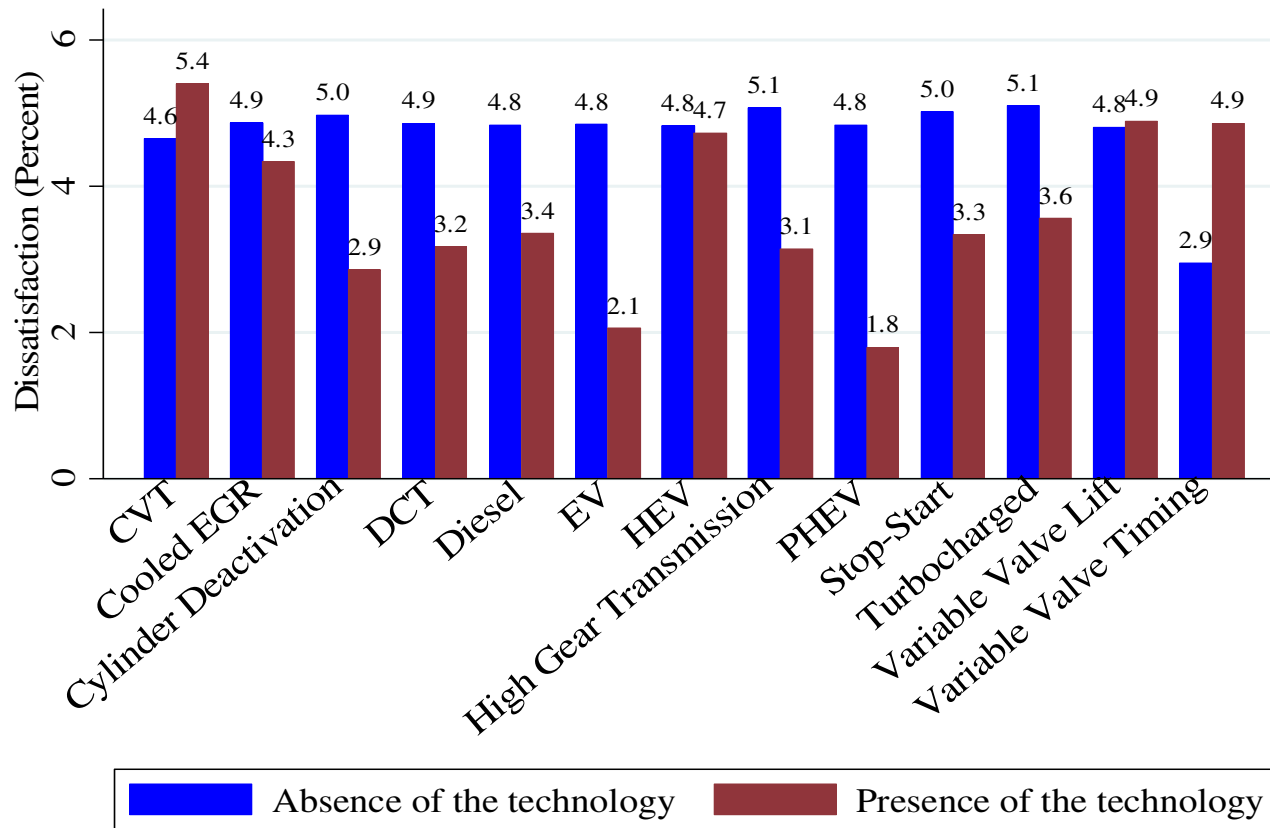
- It appears that vehicle owners are substantially more satisfied with their overall power and pickup in the presence of cylinder deactivation, diesel, EV, high gear transmission, stop-start, and turbocharged
 - Are they more dissatisfied with variable valve timing, which is applied to about 98% of the sample? We will see the importance of controlling for other factors

Percent of dissatisfaction with overall driving performance in the presence or absence of fuel-saving technology



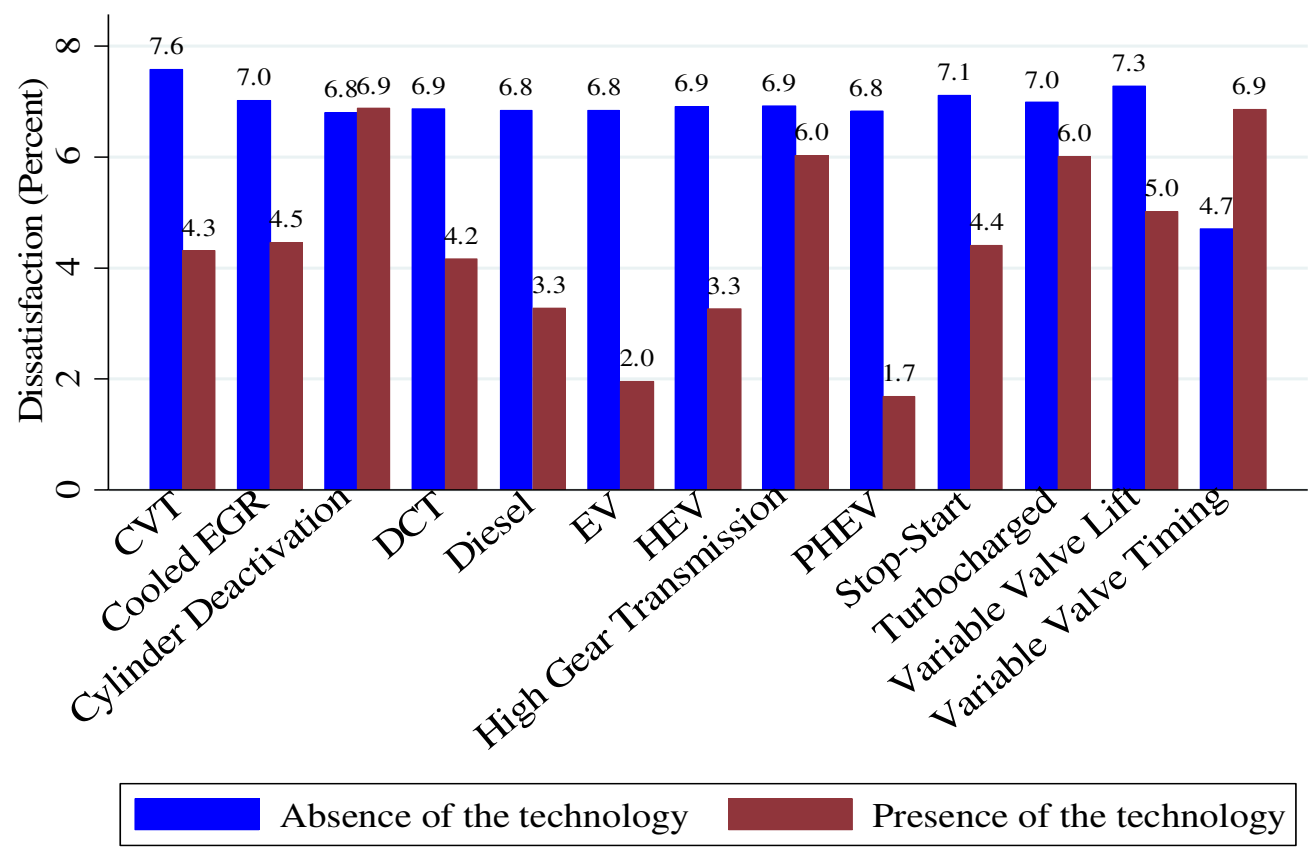
- Again, only very small percentage of vehicle buyers is not satisfied with overall driving performance

Percent of dissatisfaction with overall noise/vibration/harshness in the presence or absence of fuel-saving technology



- Again, this is a simple comparison without any controls

Percent of dissatisfaction with fuel economy/mileage in the presence or absence of fuel-saving technology



- It appears that vehicle owners are more dissatisfied with fuel economy than other operational characteristics
- Also, the differences in dissatisfaction with fuel economy between vehicle owners with and without fuel-saving technology in their vehicle are generally larger than those with other operational characteristics