Consumer Willingness to Pay for Vehicle Characteristics: What Do We Know?

David Greene,* Anushah Hossein,** Gloria Helfand,*** Robert Beach**

*University of Tennessee

**RTI International

***U.S. Environmental Protection Agency

Why study willingness to pay (WTP) for vehicle attributes?

- Related to consumer vehicle choice modeling:
  - To use such a model to estimate the effects of policy on vehicle demand, one would want to know whether the model does a reasonable job of capturing responses.
  - If models using different data or estimation methods produce similar values for WTP, then the models may have found common consumer behavioral responses
  - If models produce different estimates, then how do we know that these models are consistently modeling or predicting behavior?
- The value of knowing a value:
  - As more fuel-saving technologies are used, there may be engineering tradeoffs (or complementarities) between fuel savings & other vehicle characteristics.
  - If we identify such tradeoffs/complementarities, having WTP values would allow us to monetize the changes in values.

WTP for Vehicle Attributes

- Many researchers have estimated demand for vehicles or their characteristics
  - Typically, in discrete choice models
  - Some in hedonic models
- Different kinds of data
  - Market-level data
  - Individual revealed preference data
  - Stated preference data
- These researchers have not necessarily reported WTP values implied by their analyses
  - Having these values would facilitate comparisons across studies

Estimating WTP from existing literature

- Goal: to estimate WTP values for vehicle attributes out of as many studies as possible
  - To have available estimates of these values
  - To see whether values are reasonably consistent across studies
- We decided to focus on US-based studies, 1995-present
  - Older & foreign studies are not as likely to be relevant
- Final sample of 52 papers

Population statistics

Paper count	52
Observation count	786
Unique attribute count	146
Literature type	
Peer-reviewed	45 (86.5%)
Grey	7 (13.5%)
Data type	
Revealed preference (RP) survey	19.3%
Stated preference (SP) survey	39.3%
Market data	29.0%
Other (Joint RP-SP, literature summaries)	12.4%
Model type	
Hedonic demand	9.6%
Multinomial logit (MNL)	29.4%
Nested multinomial logit (NMNL)	13.1%
Mixed logit (MXL)	30.2%
Berry-Levinsohn-Pakes (BLP)	7.7%
Other	11.0%

Bottom line: Lots of variability

- Results vary pretty widely, not only across studies, but within studies
- Modeling results appear sensitive to a number of factors, potentially including:
    - Sources of underlying data
    - Modeling methods
    - Included & omitted variables
    - Functional form
- They suggest a lack of robustness in the measurement of these WTP values.
    - Which raises the question of the robustness of the underlying models &/or parameters

Calculating Willingness to Pay (WTP)

- For discrete choice models, we calculated it as
  - - Marginal Utility (MU) of the Attribute/MU of price
  - This is not strictly correct, because it is the ratio of two random variables
    - It is the first-order approximation in a Taylor Series expansion
    - A second-order approximation requires knowing the covariance matrix of estimates, rarely reported in publications
    - Some back-of-the-envelope calculations suggest the bias is small when coefficients are statistically significant; for non-mixed logit, the bias shrinks for more correlated coefficients
- For hedonic models, we calculated it as
  - Derivative of price with respect to the attribute
  - Also an imperfect estimate, because it is not strictly a demand-side estimate

Sources of Variability/Uncertainty

- Different studies produce different estimates
  - Sometimes one study produces multiple estimates
    - By analyzing the data multiple ways
  - Our reporting of the mean, standard deviation, and median of these estimates focuses on these central estimates
    - “Raw” results include all WTP estimates
    - “Trimmed” results drop outliers
- Each of the individual estimates of WTP has a range around it
  - We use +/- one standard error for the attribute
    - Not accounting for variation in dU/dPrice
  - Some variation is due to variation in the population
    - When price interacts with income, we use 25^{th} & 75^{th} percentiles of income distribution
    - In random effects modeling we use +/- 1 standard deviation of the attribute variable
- And there are different measures of attributes
  - E.g., fuel economy may be $/mile, miles/$, $/year, gallons/mile, miles/gallon

Example: WTP for horsepower

- 6 studies use this metric, producing 11 estimates ($/hp, 2015$)

Study	Low WTP	Central WTP	High WTP
Beresteanu & Li	-49,864.08	0.00	49,864.08
Beresteanu & Li	-55092.47	0.00	55092.47
Fifer & Bunn	31.42	39.41	47.40
Greene & Duleep	*	13.84	*
Greene & Duleep	*	13.81	*
Klier & Linn	-967.30	9.18	985.65
Klier & Linn	-109.09	1.24	111.58
Klier & Linn	-360.17	8.31	376.79
Klier & Linn	-117.03	1.33	119.70
McCarthy	297.02	355.01	412.99
Skerlos & Raichur	143.23	147.99	152.74
	Raw Mean	$53.65	
	Standard Deviation	$103.73	
	Median	$9.18	

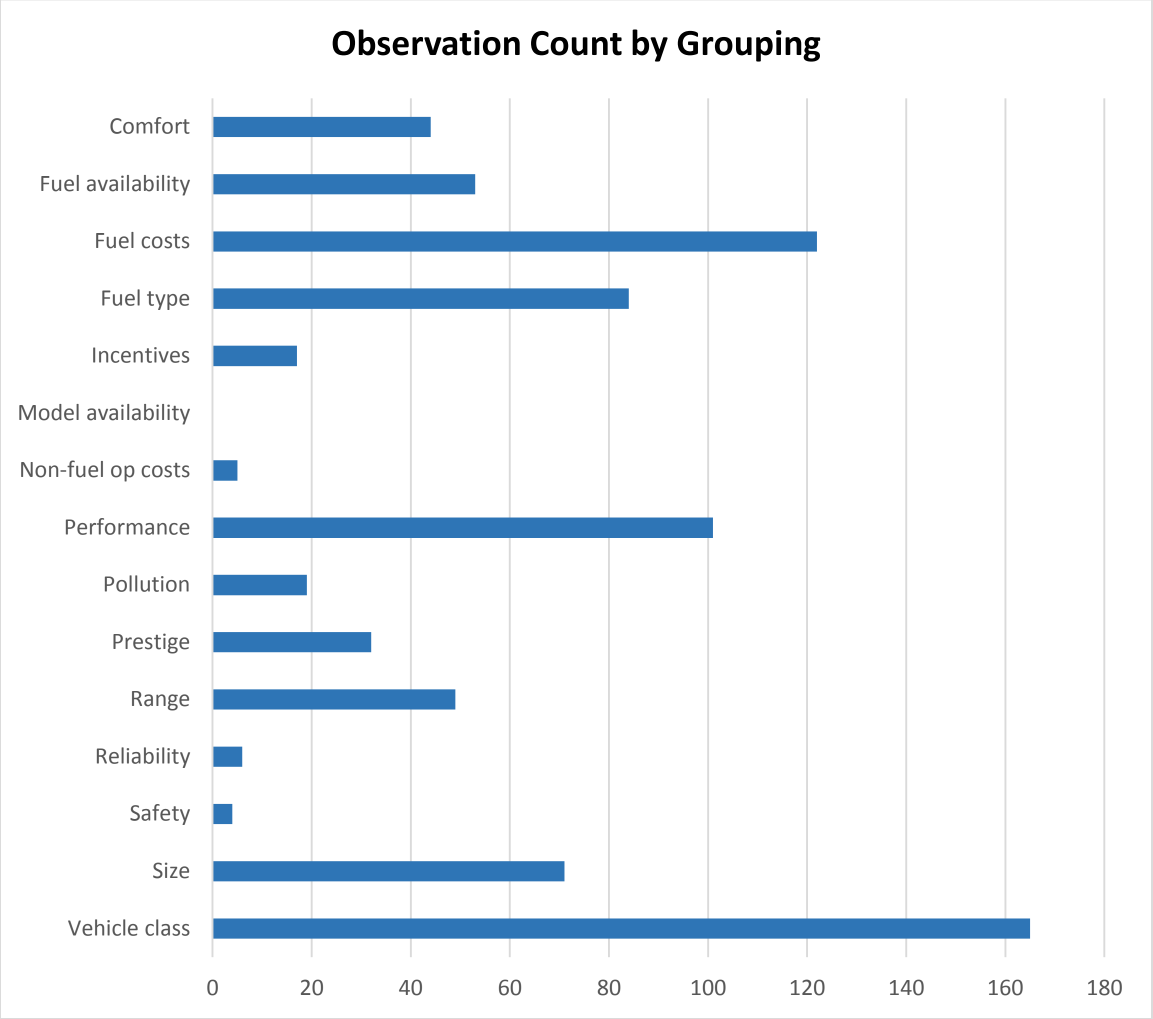
* Not enough information in the paper to calculate low & high values

- Each estimate can have a big range
- 1 study can produce different estimates
- Across studies, even more variation

A trimmed mean might drop, e.g., the 2 estimates > $100 as outliers; trimmed mean = $9.68. If you drop 4 estimates (> $100, = 0), trimmed mean = $12.45

Vehicle Characteristics

- The analysis identified 786 estimates of 146 unique attributes
- We categorized the 146 attributes into these 15 groups
  - E.g., Performance includes
    - 0-30 time
    - 0-60 time
    - Horsepower
    - Horsepower/weight
    - Top speed
- Where possible, we converted them to common units



Findings

- Following are findings on attributes with at least 6 observations

Fuel economy	Alternative fuel vehicle (AFV) range
Performance	Size
Fuel type	Comfort attributes

- Enough observations to observe variability
- Focus is on trimmed means – excluding outliers
  - This is intended to provide the best opportunity to find a robust central estimate
- Coefficient of variation as a measure of variation
  - Here, it is the dispersion of <u>central values</u> from the studies, not the variation around any one central value.
    - If the high and low WTP values are taken into consideration, variation will be much higher

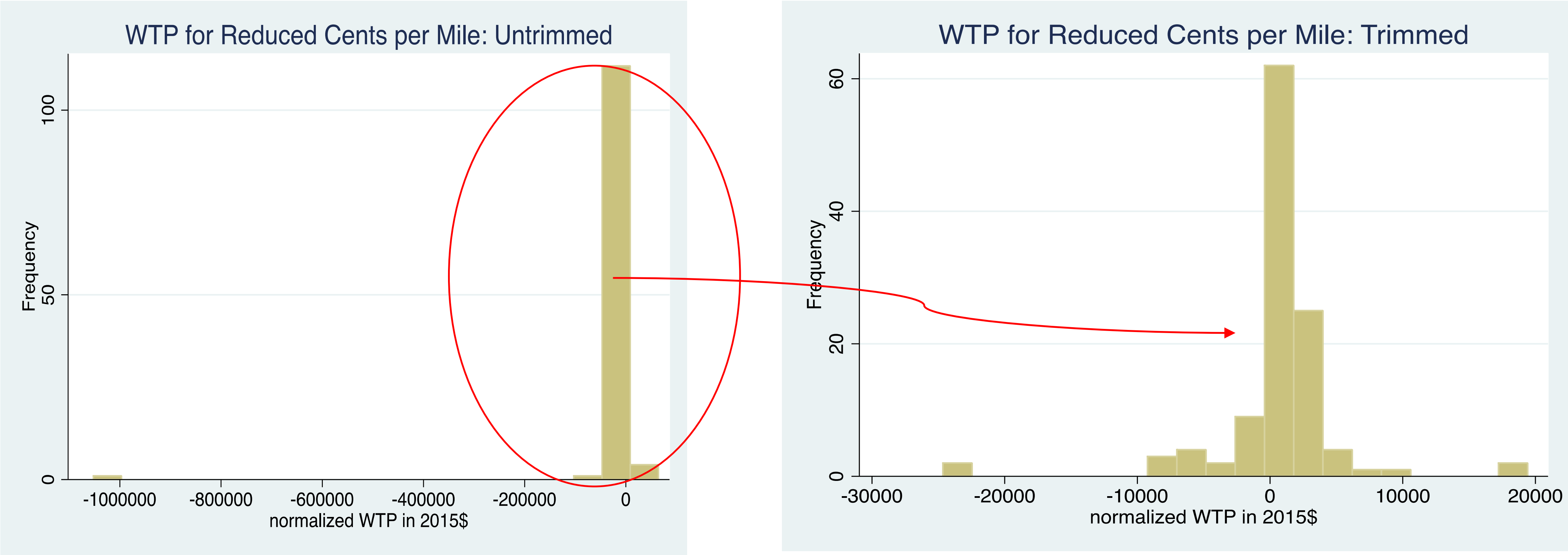
Fuel cost: Five measures of fuel economy

Measure	Present value comparison*	Trimmed Mean	Median	Coefficient of variation**
Reduce $1/year	$9/year	$26	$6	1.8 – 4.3
MPG	$450	$536	$433	1.4 – 1.4
(10) Mi/$	$1800	-$3,150	-$2,837	0.8 – 1.4
Reduce 0.01 Gal/mi	$2900	$2,666	$2,569	1.4 – 67.1
Reduce $0.01/mi	$1200	$972	$1012	2.4 – 2.6
Combined GPM and $/mi	$1200	$640	$769	11.6 – 14.9

*An order-of-magnitude calculation of the present value of a one-unit reduction in the measure, for comparison purposes.
**The smaller value represents the coefficient of variation for the trimmed mean; the larger value is the coefficient for the set of estimates including outliers.

- Different studies use different measures, which makes comparisons difficult
- Best estimates of means are not necessarily close to “present value comparison”
- Mean & median are often different, meaning that the distribution of estimates is skewed
- Quite high variation around the estimates

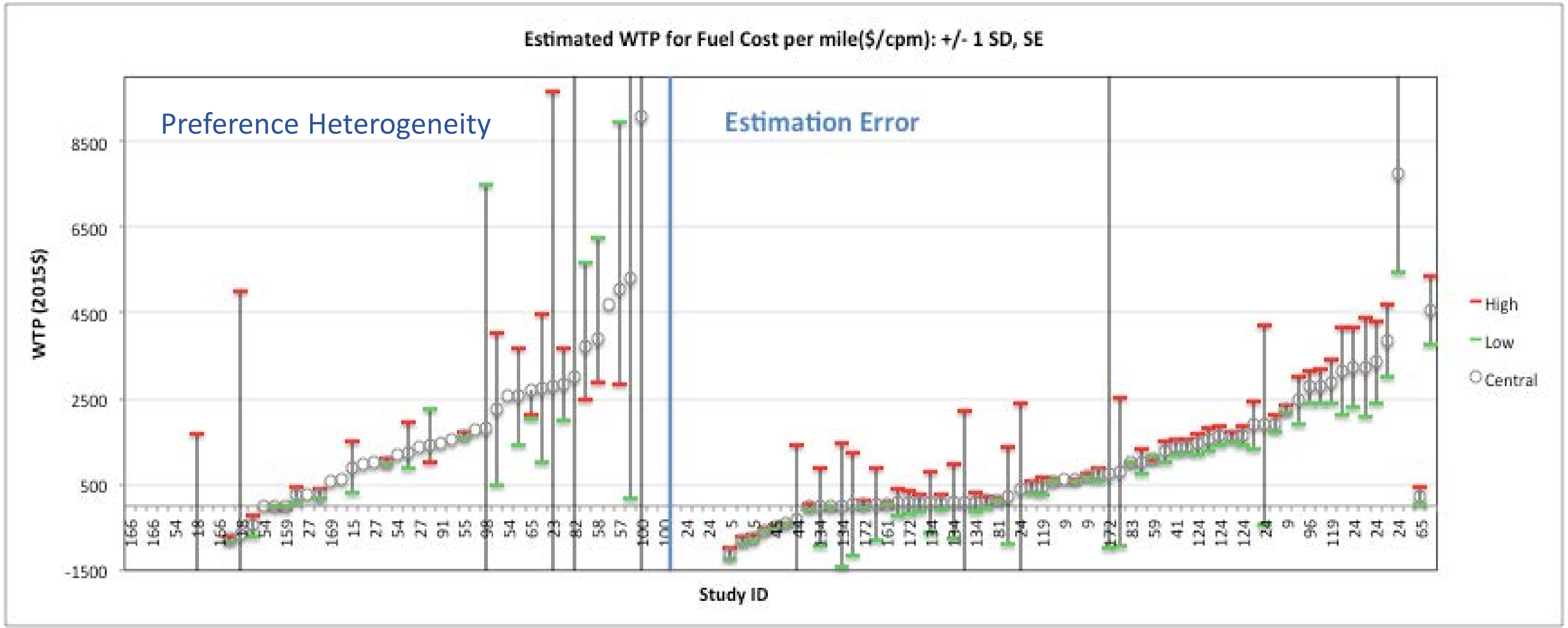
Graphical portrayal of variation in the central estimates of $0.01/mile decrease in fuel cost (2015$)



Untrimmed **Different Scales on Axes!** Trimmed

Variation in WTP for $0.01/mi decrease in fuel cost

- In some studies, variation is due to preference heterogeneity via random coefficients
- In some studies, variation is due to the standard errors about each estimate

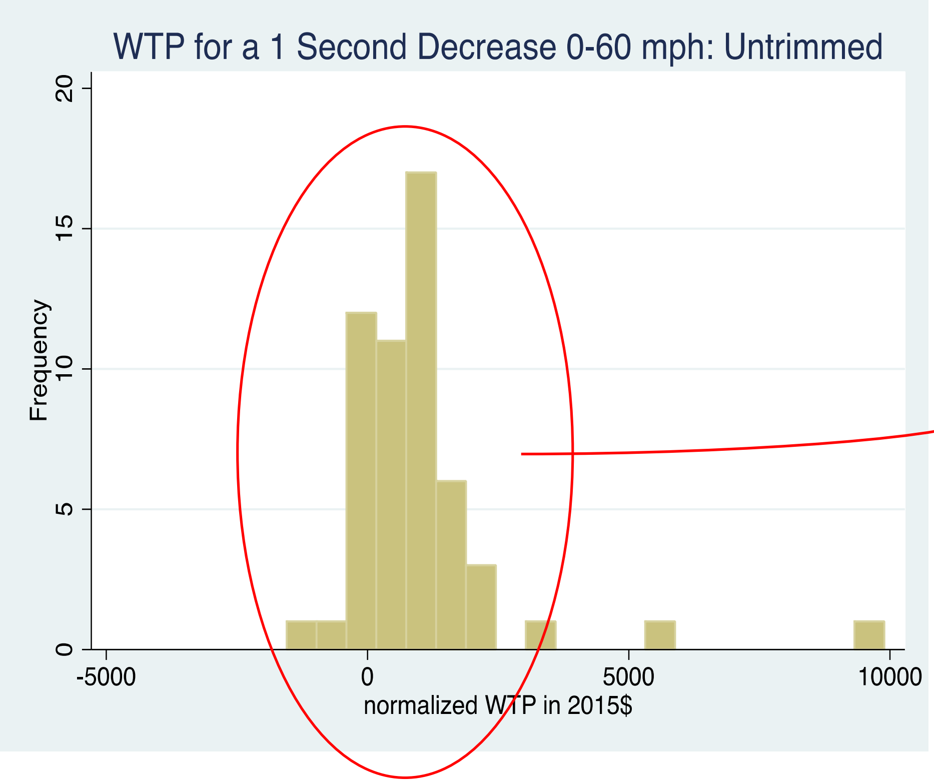


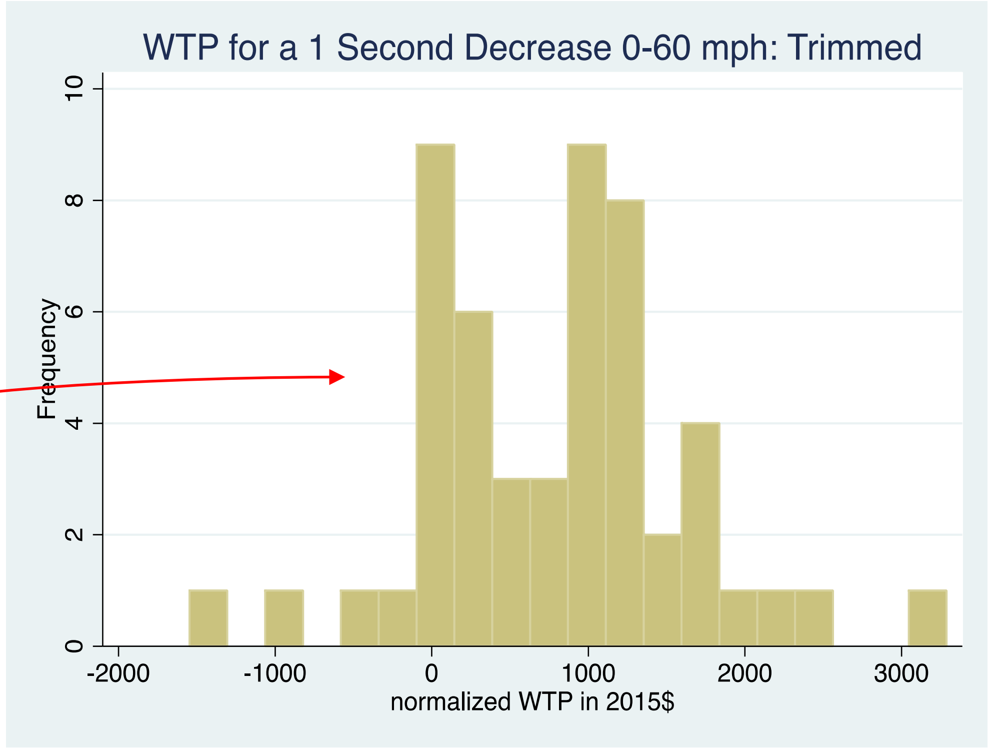
Performance: 5 measures

Measure	Trimmed Mean	Median	Coefficient of variation
Reduce 0-30 time ($/sec)	$1756	$1916	1.1
Reduce 0-to-60 time ($/sec)	$1096	$1183	0.6
Horsepower ($/hp)	$13	$10	1 – 2
Horsepower/weight [$/(0.01hp/lbs)]	$1334	$346	1.6–1.9
Top speed ($/mph)	$100	$75	0.6

Performance: central tendencies, normalized to 0-to-60

- Combining 0-30 time, 0-60 time, hp/wt., via conversion factors

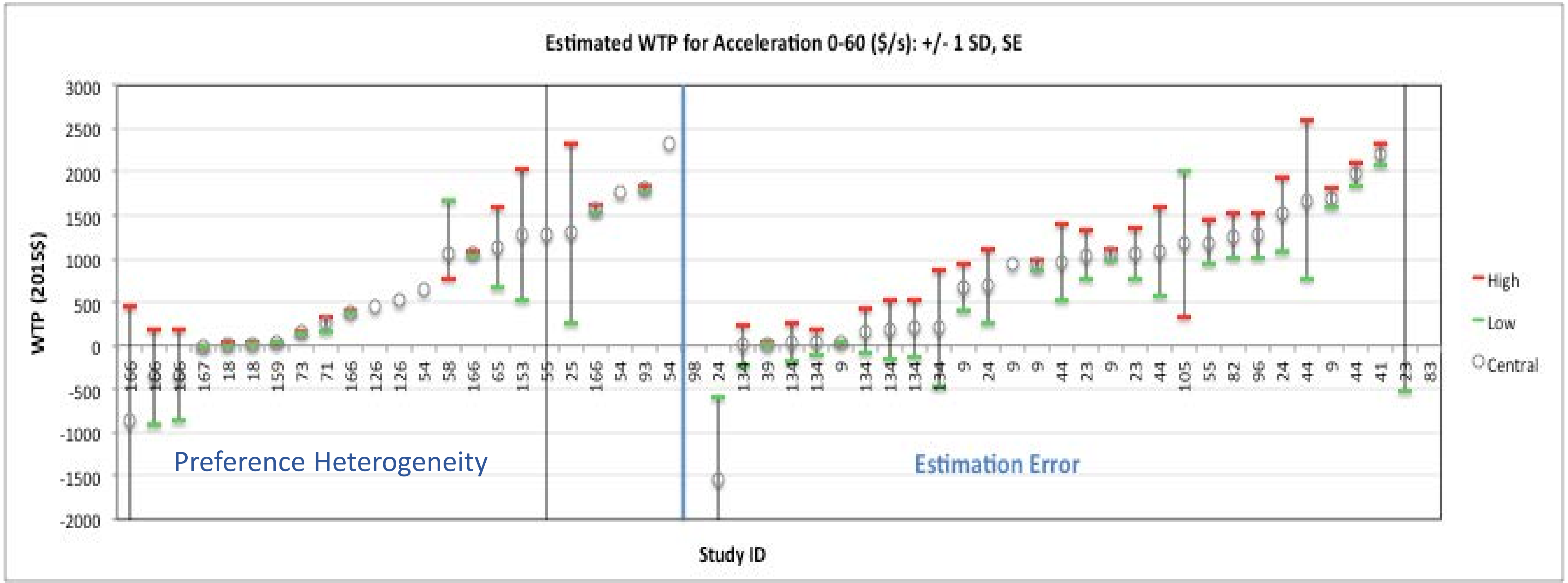




Untrimmed **Different Scales on Axes!** Trimmed

Variation in Value for a One Second Decrease in 0-60 Time

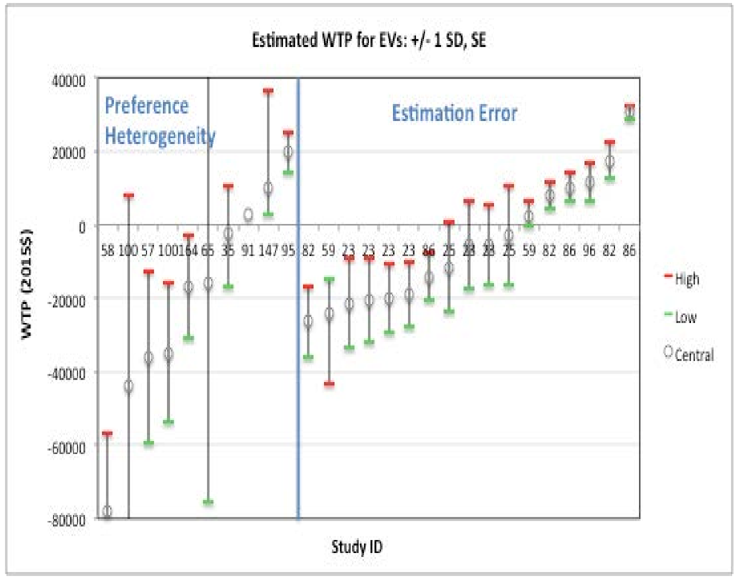
- In some studies, variation is due to the uncertainty about each estimate
- In some studies, variation is due to population variation – e.g., in income, via random coefficients



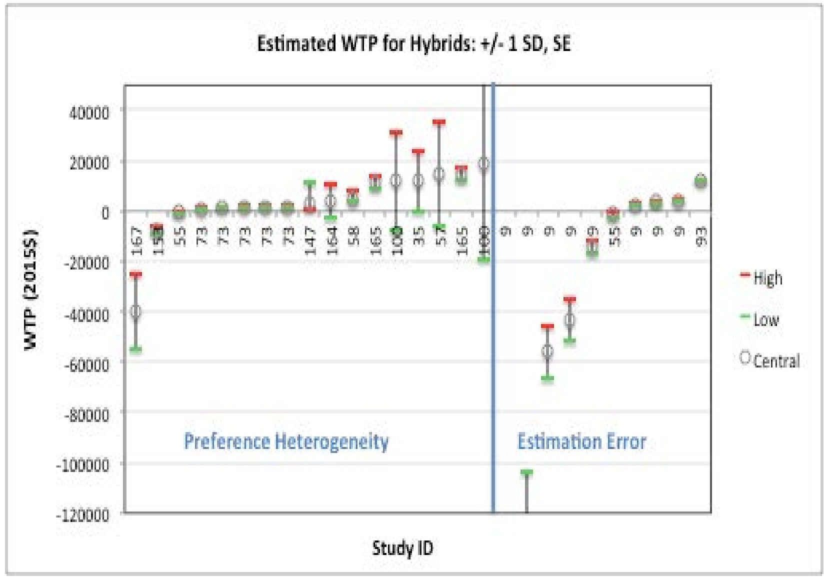
Fuel type

Measure	Trimmed Mean	Median	Coefficient of variation
EVs	-$10,526	-$11,392	2.2
Hybrids	-$1,437	+$2,375	3.5-12.9
Natural gas	-$5,620	+$4,620	4.2

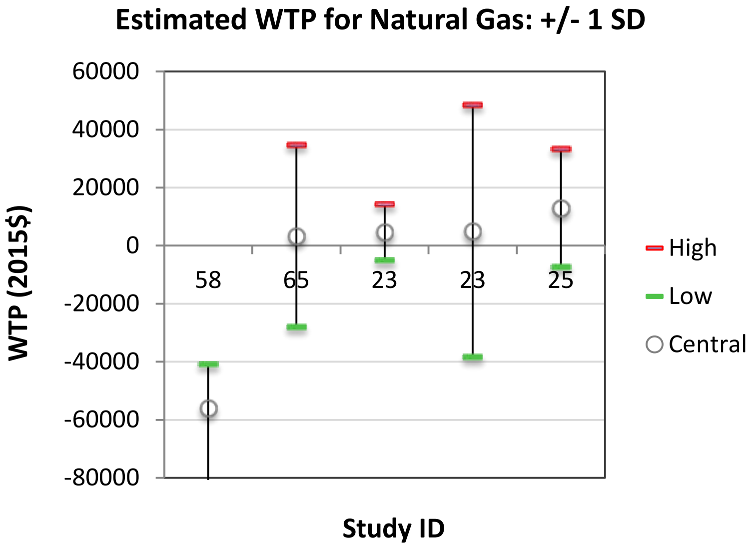
EVs



HEVs



NGVs



Alternative Fuel Vehicle Range

Measure	Trimmed Mean	Median	Coefficient of variation
Range	$7	$60	19.1

Size

Measure	Trimmed Mean	Median	Coefficient of variation
Footprint	$3404	$2283	1.3-4.0
Luggage space	$1445	$1100	0.9-2.3
Weight	$6	$1	1.4-2.0

Comfort attributes

Measure	Trimmed Mean	Median	Coefficient of variation
Automatic transmission (vs. manual)	$1760	$1522	2.1
All-wheel drive	$32,031	$26,779	0.6
Air conditioning	$1085	$4177	2.8
Shoulder room	$1085	$592	1.3

Summary

- This study contributes estimates of WTP for a variety of vehicle characteristics from a number of studies
- Results vary pretty widely, not only across studies, but within studies
- Modeling results appear sensitive to a number of factors, e.g.,
  - Sources of underlying data
  - Modeling methods
  - Included & omitted variables
  - Functional form
  - Measure
- They suggest a lack of robustness in the measurement of these WTP values.
  - Which raises the question of robustness in the underlying models &/or parameters

Implications

- Consumer choice modeling
  - It suggests that current models, and modeling approaches, can produce quite different results due to what might seem like minor changes
  - It would be helpful if researchers calculated & presented these values themselves
    - To facilitate comparisons
    - Or, they could provide sufficient information for others to calculate these values
- Estimating opportunity costs or ancillary benefits of changes in vehicle attributes, especially those other than fuel economy
  - It's not clear that these estimates are informative about these characteristics
  - There may be reasons to doubt that these studies are even estimating what they claim to estimate
    - E.g., is willingness to pay for fuel economy partly capturing effects of size and quality, since high fuel economy was historically associated with smaller, lower-quality cars?
      - Pre-footprint-based standards
  - It's possible that deeper digging might produce more sensible results
    - E.g., perhaps there's a trend in the value of performance over time, that this analysis won't recognize

Appendix

All values are in 2015$

					Raw		Trimmed			
Grouping	**Attribute**	**N**	**Units**	**Outliers**	**Mean**	**SD**	**Mean**	**SD**	**Median**	**Skew**
Comfort	Auto-transmission	9	0/1	1	1760	3669	823	2518	1111	0.74
	Front wheel drive	6	0/1	0	-32031	18031	-32031	18031	-26779	1.20
	Air conditioning	13	0/1	0	3521	9544	3521	9544	4177	0.84
	Shoulder room	12	$/inch	1	1085	1394	705	479	546	1.29
Fuel costs	Cost per mile	58	$/cpm	2	-1251	3441	-1291	1194	-1147	1.13
	Cost per year	13	$/($/yr)	1	-67	156	-26	50	-6	4.47
	Gallons per mile	20	$/0.01gpm	4	14354	76395	-7972	18740	-580	13.74
	Miles per dollar	8	$/(10mi/$)	1	-20181	27869	-11542	14477	-4216	2.74
	Miles per gallon	10	$/mpg	1	365	659	174	281	64	2.70
Fuel type	Electric vehicle	24	0/1	1	-16515	21283	-13851	17191	-16837	0.82
	Hybrid	28	0/1	2	-11727	44322	-852	18441	2796	-0.30
	Natural gas	7	0/1	2	-5620	23691	6187	3851	5006	1.24
Performance	Acceleration (0-30)	11	$/s	0	-1756	1886	-1756	1886	-1916	0.92
	Acceleration (0-60)	8	$/s	0	-1096	627	-1096	627	-1183	0.93
	Horsepower	11	$/hp	4	54	109	13	13	10	1.32
	HP/weight	29	0.01hp/lbs	1	1861	3523	1334	2126	346	3.85
	Top speed	9	$/mph	0	100	58	100	58	75	1.33
AFV Range	Range	23	$/mi	2	89	41	97	32	98	1.00
Size	Footprint	17	$/ft^2	1	43401	163103	3856	4442	3273	1.18
	Luggage space	12	$/ft^3	1	4209	9655	1445	1310	1100	1.31
	Weight	19	$/lb	1	10	20	6	8	1	11.14

When Raw Mean differs strongly from Trimmed Mean, outliers matter.

When Trimmed Mean differs from Median, the distribution of estimates is skewed.

Median may be better than mean for a skewed distribution.

Large standard deviations indicate variation in estimates.

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