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

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**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

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Paper count</td>
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<td>Observation count</td>
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<td>Unique attribute count</td>
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### Literature type

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<tr>
<td>Grey</td>
<td>7 (13.5%)</td>
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### Data type

<table>
<thead>
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<td>Revealed preference (RP) survey</td>
<td>19.3%</td>
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<tr>
<td>Stated preference (SP) survey</td>
<td>39.3%</td>
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<tr>
<td>Market data</td>
<td>29.0%</td>
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<tr>
<td>Other (Joint RP-SP, literature summaries)</td>
<td>12.4%</td>
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### Model type

<table>
<thead>
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<tbody>
<tr>
<td>Hedonic demand</td>
<td>9.6%</td>
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<tr>
<td>Multinomial logit (MNL)</td>
<td>29.4%</td>
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<tr>
<td>Nested multinomial logit (NMNL)</td>
<td>13.1%</td>
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<tr>
<td>Mixed logit (MXL)</td>
<td>30.2%</td>
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<tr>
<td>Berry-Levinsohn-Pakes (BLP)</td>
<td>7.7%</td>
</tr>
<tr>
<td>Other</td>
<td>11.0%</td>
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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 25th & 75th 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 ($/hp, 2015$)

<table>
<thead>
<tr>
<th>Study</th>
<th>Low WTP</th>
<th>Central WTP</th>
<th>High WTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beresteanu &amp; Li</td>
<td>-49,864.08</td>
<td>0.00</td>
<td>49,864.08</td>
</tr>
<tr>
<td>Beresteanu &amp; Li</td>
<td>-55,092.47</td>
<td>0.00</td>
<td>55,092.47</td>
</tr>
<tr>
<td>Fifer &amp; Bunn</td>
<td>31.42</td>
<td>39.41</td>
<td>47.40</td>
</tr>
<tr>
<td>Greene &amp; Duleep</td>
<td>*</td>
<td>13.84</td>
<td>*</td>
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<tr>
<td>Greene &amp; Duleep</td>
<td>*</td>
<td>13.81</td>
<td>*</td>
</tr>
<tr>
<td>Klier &amp; Linn</td>
<td>-967.30</td>
<td>9.18</td>
<td>985.65</td>
</tr>
<tr>
<td>Klier &amp; Linn</td>
<td>-109.09</td>
<td>1.24</td>
<td>111.58</td>
</tr>
<tr>
<td>Klier &amp; Linn</td>
<td>-360.17</td>
<td>8.31</td>
<td>376.79</td>
</tr>
<tr>
<td>Klier &amp; Linn</td>
<td>-117.03</td>
<td>1.33</td>
<td>119.70</td>
</tr>
<tr>
<td>McCarthy</td>
<td>297.02</td>
<td>355.01</td>
<td>412.99</td>
</tr>
<tr>
<td>Skerlos &amp; Raichur</td>
<td>143.23</td>
<td>147.99</td>
<td>152.74</td>
</tr>
</tbody>
</table>

- 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

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

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

*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 $0.01/mile decrease in fuel cost (2015$)
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

<table>
<thead>
<tr>
<th>Measure</th>
<th>Trimmed Mean</th>
<th>Median</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce 0-30 time ($/sec)</td>
<td>$1756</td>
<td>$1916</td>
<td>1.1</td>
</tr>
<tr>
<td>Reduce 0-to-60 time ($/sec)</td>
<td>$1096</td>
<td>$1183</td>
<td>0.6</td>
</tr>
<tr>
<td>Horsepower ($/hp)</td>
<td>$13</td>
<td>$10</td>
<td>1 – 2</td>
</tr>
<tr>
<td>Horsepower/weight [$/0.01hp/lbs]</td>
<td>$1334</td>
<td>$346</td>
<td>1.6–1.9</td>
</tr>
<tr>
<td>Top speed ($/mph)</td>
<td>$100</td>
<td>$75</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Performance: central tendencies, normalized to 0-to-60

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

Untrimmed vs. Trimmed

Different Scales on Axes!
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

Preference Heterogeneity

Estimation Error

Estimated WTP for Acceleration 0-60 ($/s): +/- 1 SD, SE
## Fuel type

<table>
<thead>
<tr>
<th>Measure</th>
<th>Trimmed Mean</th>
<th>Median</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVs</td>
<td>-$10,526</td>
<td>-$11,392</td>
<td>2.2</td>
</tr>
<tr>
<td>Hybrids</td>
<td>-$1,437</td>
<td>+$2,375</td>
<td>3.5-12.9</td>
</tr>
<tr>
<td>Natural gas</td>
<td>-$5,620</td>
<td>+$4,620</td>
<td>4.2</td>
</tr>
</tbody>
</table>

### EVs

![Estimated WTP for EVs: +/- 1 SD, SE](image1)

### HEVs

![Estimated WTP for Hybrids: +/- 1 SD, SE](image2)

### NGVs

![Estimated WTP for Natural Gas: +/- 1 SD](image3)

March 16 2017 Draft -- Subject to Revision
### Alternative Fuel Vehicle Range

<table>
<thead>
<tr>
<th>Measure</th>
<th>Trimmed Mean</th>
<th>Median</th>
<th>Coefficient of variation</th>
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</thead>
<tbody>
<tr>
<td>Range</td>
<td>$7</td>
<td>$60</td>
<td>19.1</td>
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</table>

### Size

<table>
<thead>
<tr>
<th>Measure</th>
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<th>Median</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footprint</td>
<td>$3404</td>
<td>$2283</td>
<td>1.3-4.0</td>
</tr>
<tr>
<td>Luggage space</td>
<td>$1445</td>
<td>$1100</td>
<td>0.9-2.3</td>
</tr>
<tr>
<td>Weight</td>
<td>$6</td>
<td>$1</td>
<td>1.4-2.0</td>
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</table>

### Comfort attributes

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

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Attribute</th>
<th>N</th>
<th>Units</th>
<th>Outliers</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Skew</th>
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<tr>
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<td>Auto-transmission</td>
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<td>3669</td>
<td>823</td>
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<td>0</td>
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<td>$/inch</td>
<td>1</td>
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<td>1394</td>
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<td>479</td>
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<td>$/($/yr)</td>
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<td>156</td>
<td>-26</td>
<td>50</td>
<td>-6</td>
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<td></td>
<td>Gallons per mile</td>
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<td>$/0.01gpm</td>
<td>4</td>
<td>14354</td>
<td>76395</td>
<td>-7972</td>
<td>18740</td>
<td>-580</td>
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<td></td>
<td>Miles per dollar</td>
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<td>$/(10mi/$)</td>
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<td>10</td>
<td>$/mpg</td>
<td>1</td>
<td>365</td>
<td>659</td>
<td>174</td>
<td>281</td>
<td>64</td>
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<td>Fuel type</td>
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<td>Hybrid</td>
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<td>44322</td>
<td>-852</td>
<td>18441</td>
<td>2796</td>
<td>-0.30</td>
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<tr>
<td></td>
<td>Natural gas</td>
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<td>0/1</td>
<td>2</td>
<td>-5620</td>
<td>23691</td>
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<td>3851</td>
<td>5006</td>
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<td>Performance</td>
<td>Acceleration (0-30)</td>
<td>11</td>
<td>$/s</td>
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<td>1886</td>
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<td>1886</td>
<td>-1916</td>
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<td></td>
<td>Acceleration (0-60)</td>
<td>8</td>
<td>$/s</td>
<td>0</td>
<td>-1096</td>
<td>627</td>
<td>-1096</td>
<td>627</td>
<td>-1183</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>Horsepower</td>
<td>11</td>
<td>$/hp</td>
<td>4</td>
<td>54</td>
<td>109</td>
<td>13</td>
<td>13</td>
<td>10</td>
<td>1.32</td>
</tr>
<tr>
<td></td>
<td>HP/weight</td>
<td>29</td>
<td>0.01hp/lbs</td>
<td>1</td>
<td>1861</td>
<td>3523</td>
<td>1334</td>
<td>2126</td>
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<td>AFV Range</td>
<td>Range</td>
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<td>$/mi</td>
<td>2</td>
<td>89</td>
<td>41</td>
<td>97</td>
<td>32</td>
<td>98</td>
<td>1.00</td>
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<tr>
<td>Size</td>
<td>Footprint</td>
<td>17</td>
<td>$/ft^2</td>
<td>1</td>
<td>43401</td>
<td>163103</td>
<td>3856</td>
<td>4442</td>
<td>3273</td>
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</tr>
<tr>
<td></td>
<td>Luggage space</td>
<td>12</td>
<td>$/ft^3</td>
<td>1</td>
<td>4209</td>
<td>9655</td>
<td>1445</td>
<td>1310</td>
<td>1100</td>
<td>1.31</td>
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<tr>
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<td>Weight</td>
<td>19</td>
<td>$/lb</td>
<td>1</td>
<td>10</td>
<td>20</td>
<td>6</td>
<td>8</td>
<td>1</td>
<td>11.14</td>
</tr>
</tbody>
</table>

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.
Studies included


Studies included, continued


Studies included, continued


