Content

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- Survey design and results
- Modeling framework
- Results
- Ongoing efforts and future work
Introduction - Truck Fleet

- There were more than 273 million on-road vehicles in the US in 2018
- Trucks account for about 4.8% of all vehicles
  - 2.9 millions (1.06%) combination trucks (this share (the purple curve) has not significantly changed over time)
  - 10.3 millions (3.77%) single unit trucks

Source: BTS
Introduction - Truck VMT

• However, the story is different when it comes to VMT!
• Total VMT in 2018: 3,240 (billion)
• Freight vehicles account for about 9.4% of total VMT (compare to 4.8% vehicle share)
  – Share of combination trucks: 5.68% (compare to 1.06% vehicle share). This share (the purple curve) has increased over time
  – Share of single unit trucks: 3.72%

Source: BTS
Multiple highly automated technologies for trucks are emerging.

- **Active Braking Systems**
  - Automatic emergency braking
  - Air disc brakes
  - Adaptive cruise control

- **Active Steering Systems**
  - Lane keep assist
  - Lane centering
  - Adaptive steering control

- **Active Warning Systems**
  - Lane departure
  - Forward collision
  - Blind spot detection

- **Camera Monitoring Systems**
  - In-cab facing driver training
  - Forward facing event recording
  - Side rear-view for mirrors

Source: ATRI
Motivation

• Share of future truck VMT could be higher
  – Considering less stress of driving and larger time windows

• Reduced transportation cost impact
  – Driver cost vs. technology cost

• Complexity of investment
  – Among small, medium and large companies

• Industry perceptions of highly automated trucks-critically important
Data

• National truck fleet ownership companies
  – Categorization based on employee size
  – Small (<50), medium (50-500) and large (>500)

• A stated preference survey (more next slide)

• Sample size consideration
  – Difficult to obtain sample size
  – Cochran’s and Yamane’s method - min. of 400 samples
Survey Data Collection

- On Qualtrics and paid for time
- Over a period of two weeks in July 2020
- Time for survey completion 10-15 min
- 60 questions
  - Respondents' socio-economic characteristics
  - Company characteristics
  - Preferences
- Administered for quality check and quick completion
Survey Results (1)

**AGE**
- Under 25 years: 5%
- 26-30 years: 9%
- 31-35 years: 10%
- 36-40 years: 17%
- 41-45 years: 14%
- 46-50 years: 13%
- 51-60 years: 10%
- 61-75 years: 12%
- Over 75 years: 10%

**EDUCATION**
- High school or GED: 22%
- Associate’s degree: 14%
- Bachelor’s degree: 26%
- Master’s or Doctorate degree: 10%
- Professional degree: 8%
- Some college credit, no degree: 20%

**NUMBER OF DRIVERS**
- 1-10 years: 14%
- 11-50 years: 21%
- 51-100 years: 16%
- 101-250 years: 8%
- 251-500 years: 9%
- 501-1000 years: 10%
- 1001-2500: 6%
- Over 2500: 16%

**AREA OF BUSINESS**
- Northeast: 15%
- South: 24%
- Midwest: 23%
- South: 24%
- Southwest: 18%

**YRS. IN COMPANY**
- 1-2 years: 18%
- 3-5 years: 23%
- 6-10 years: 19%
- 11-15 years: 13%
- 16-20 years: 9%
- 21-25 years: 4%
- Over 25 years: 16%
- Less than one year: 8%
Stated Preferences

- Four scenarios are developed based on *additional* cost of automation (Level 1 and regular trucks are baseline)

<table>
<thead>
<tr>
<th>Level of Autonomy</th>
<th>Scenario-1</th>
<th>Scenario-2</th>
<th>Scenario-3</th>
<th>Scenario-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2</td>
<td>$10,000</td>
<td>$7,500</td>
<td>$5,000</td>
<td>$2,500</td>
</tr>
<tr>
<td>Level 3</td>
<td>$20,000</td>
<td>$15,000</td>
<td>$10,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>Level 4</td>
<td>$30,000</td>
<td>$22,500</td>
<td>$15,000</td>
<td>$7,500</td>
</tr>
<tr>
<td>Level 5</td>
<td>$40,000</td>
<td>$30,000</td>
<td>$20,000</td>
<td>$10,000</td>
</tr>
</tbody>
</table>
Stated Preference in the Survey

Example of Scenario-4 in the survey

What would your company or you as owner-operator choose if the additional costs of automated technologies are as follows?

<table>
<thead>
<tr>
<th>Autonomous Technology</th>
<th>Level 0 &amp; 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver needed (cost reduction if driver is eliminated)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Platooning capabilities (max. 6% fuel economy)</td>
<td>No</td>
<td>No</td>
<td>Some</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Capability to sync with other vehicles and traffic signals (max. 5% fuel cost reduction)</td>
<td>No</td>
<td>Low</td>
<td>Some</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Safety benefits (max. 10% fewer crashes)</td>
<td>No</td>
<td>Low</td>
<td>Some</td>
<td>High</td>
<td>Full</td>
</tr>
<tr>
<td>More productivity (extending HOS beyond 11 hrs/day)</td>
<td>No</td>
<td>No</td>
<td>Low</td>
<td>Some</td>
<td>High</td>
</tr>
<tr>
<td>Additional cost of highly automated technologies</td>
<td>None</td>
<td>$2,500</td>
<td>$5,000</td>
<td>$7,500</td>
<td>$10,000</td>
</tr>
</tbody>
</table>
Willingness to Pay (stated) - By Firm Size

Scenario 1

- Level 2: $10,000
- Level 3: $20,000
- Level 4: $30,000
- Level 5: $40,000
- Standard

Percent of Organizations

- Small
- Medium
- Large

Scenario 2

- Level 2: $7,500
- Level 3: $15,000
- Level 4: $22,500
- Level 5: $30,000
- Standard

Percent of Organizations

- Small
- Medium
- Large

Scenario 3

- Level 2: $5,000
- Level 3: $10,000
- Level 4: $15,000
- Level 5: $20,000
- Standard

Percent of Organizations

- Small
- Medium
- Large

Scenario 4

- Level 2: $2,500
- Level 3: $5,000
- Level 4: $7,500
- Level 5: $10,000
- Standard

Percent of Organizations

- Small
- Medium
- Large

Scenario 1 Most Expensive

Scenario 4 Least Expensive
Methodology (1)

• Choice modeling framework for analyzing SP data
• Utility of choosing alternative \( i \) for firm \( n \): \( U_{ni} = V_{ni} + \varepsilon_{ni} \)
  – \( V_{ni} \) is known up to some parameters (i.e., \( V_{ni} = \beta x_{ni} \))
  – \( \varepsilon_{n} \) is the error term
• Each \( \varepsilon_{ni} \) is independently, identically distributed
• If we assume that the distribution is Gumbel (Extreme Value type I), then the model is MNL
• Probability of firm \( n \) choosing alternative \( i \) can be given as
  \[
P_{ni} = \frac{e^{V_{ni}}}{\sum_i e^{V_{nj}}} = \frac{e^{\beta x_{ni}}}{\sum_j e^{\beta x_{nj}}}
\]
Methodology (2)

- Mixed logit models obviate the three limitations of MNL
  - random taste variation,
  - unrestricted substitution patterns, and
  - correlation in unobserved factors over time
- Let the utility of choosing alternative $i$ for person $n$ be: $U_{ni} = \beta_n x_{ni} + \epsilon_{ni}$
  - $\beta_n$ is a vector of coefficients for person $n$
  - $\beta$ varies over decision makers in the population with density $f(\beta)$
- $P_{ni}|\beta_n = \frac{e^{\beta_n x_{ni}}}{\sum_j e^{\beta_n x_{nj}}}$, $\beta_n$ is unknown; thus we cannot condition on $\beta$
- Unconditional probability (or mixed logit probability): $P_{ni} = \int \left( \frac{e^{\beta_n x_{ni}}}{\sum_j e^{\beta_n x_{nj}}} \right) f(\beta) d\beta$
- A distribution (typically normal) is specified for the coefficients and the parameters of that distribution are estimated
Findings and Results - Model Types

- For each cost scenario, three models are developed

<table>
<thead>
<tr>
<th>Model #</th>
<th>Model Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model-1</td>
<td>Alternative-specific cost: MNL</td>
</tr>
<tr>
<td>Model-2</td>
<td>Generic cost: MNL</td>
</tr>
<tr>
<td>Model-3</td>
<td>Individual-specific cost: Mixed Logit</td>
</tr>
</tbody>
</table>

- In total 12 models (4 scenarios * 3 models/scenario)
- Consistent with the relevant literature, MXL models are developed based on 1,000 draws for each individual.
- Random draw example-age:
  - we assign a random age uniform distribution between start and end values
Findings and Results - Effect of Age

- Significant variables in Scenario 1, with Mod1 - Age
  - Age is significant for all alternatives, except for Level 5
  - Age has negative impact on adoption of higher levels of automation which means the higher the age of individual, the higher his/her negative impression about Levels 3-5 of automation.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Est</th>
<th>Std Err</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age_Lev1</td>
<td>0.0222</td>
<td>0.00901</td>
<td>0.014</td>
</tr>
<tr>
<td>Age_Lev2</td>
<td>0.0157</td>
<td>0.00916</td>
<td>0.0994</td>
</tr>
<tr>
<td>Age_Lev3</td>
<td>-0.0298</td>
<td>0.00953</td>
<td>0.00384</td>
</tr>
<tr>
<td>Age_Lev4</td>
<td>-0.0434</td>
<td>0.0107</td>
<td>6.04E-05</td>
</tr>
<tr>
<td>Age_Lev5</td>
<td>-0.013</td>
<td>0.0134</td>
<td>0.323</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Est</th>
<th>Std Err</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age_Lev1</td>
<td>0.0143</td>
<td>0.009</td>
<td>0.113</td>
</tr>
<tr>
<td>Age_Lev2</td>
<td>0.00786</td>
<td>0.00916</td>
<td>0.411</td>
</tr>
<tr>
<td>Age_Lev3</td>
<td>-0.0377</td>
<td>0.00954</td>
<td>0.00026</td>
</tr>
<tr>
<td>Age_Lev4</td>
<td>-0.0513</td>
<td>0.0107</td>
<td>2.17E-06</td>
</tr>
<tr>
<td>Age_Lev5</td>
<td>-0.0209</td>
<td>0.0134</td>
<td>0.112</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Est</th>
<th>Std Err</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age_Lev1</td>
<td>0.115</td>
<td>0.0198</td>
<td>1.89E-10</td>
</tr>
<tr>
<td>Age_Lev2</td>
<td>0.0984</td>
<td>0.0126</td>
<td>2.89E-15</td>
</tr>
<tr>
<td>Age_Lev3</td>
<td>0.0449</td>
<td>0.00998</td>
<td>2.09E-05</td>
</tr>
<tr>
<td>Age_Lev4</td>
<td>0.0233</td>
<td>0.0144</td>
<td>0.0799</td>
</tr>
<tr>
<td>Age_Lev5</td>
<td>0.048</td>
<td>0.0217</td>
<td>0.0167</td>
</tr>
</tbody>
</table>
Findings and Results - Effect of Ownership Status

- **Vehicle ownership status**
  - Own (only for Level 1): negative coefficient, always significant at *p-value* of 1%
  - Contract (only for Level 1): negative coefficient, always significant at *p-value* of 10%
  - Companies owning vehicles can hardly incur the cost of buying autonomous trucks
  - The absolute value of B_Own is about two times of that of B_Contract
    - Strong resistance of fleet owners to adopt higher level of automation
Findings and Results - Effect of Education

- **Education**
  - Some college credit, no degree
    - Prefer Level 2 (positive likelihood with coefficient less than 1)
  - Associate's degree
    - Prefer Level 3 (positive likelihood with coefficient less than 1)
  - Professional degree, trade, technical, or vocational training
    - Prefer Level 4 and 5 compared to lower levels (positive likelihood with coefficient less than 1)
    - Focusing on Mod-3, the coefficient decreases as we move from scenario 1 to scenario 4 suggesting that the impact of this education level on adoption likelihood increases with lowering technology cost which makes sense
  - All significant at 5% level in all scenarios and with all models
Findings and Results - Geographic Region

- **Geographical variables**
  - Midwest: higher significance for Level 5 (always at \( p\text{-value} \) 5%)
  - Northwest: higher significance for Level 5 (at \( p\text{-value} \) 10% with Mod1 and Mod2, and at 20% with Mod3 in all scenarios)
  - South: only significant for Level 1 (always at \( p\text{-value} \) 5%) - conservative approach in Southern states?
  - Southwest: higher significance for Level 3 (always at \( p\text{-value} \) 10%)
Findings and Results- Employment Time at Firm

• Employment time
  – If employment time is less than two years - say Type 1 Tenure
    • Higher inclination towards Level 2 automation (always significant at $p$-value 5%)
  – If employment time us between 5-10 years - say Type 2 Tenure
    • Higher inclination towards Level 5 automation (always significant at $p$-value 5%)
  – The intensity of preference of Type 2 Tenure is twice as that of Type 1 Tenure
  – Higher experience than Type 2 Tenure are not significant
    • May be lower sample size or need of additional data
Findings and Results - Goodness-of-fit

- Overall, a model with generic cost (i.e., Mod 2 or 3) offers a better fit.
- Based on BIC, Mod2 is the based while Mod3 is the based if AIC is considered.
- The differences are not significant representing model results are comparable.

<table>
<thead>
<tr>
<th>Goodness-of-fit</th>
<th>Model #</th>
<th>Model Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure</td>
<td>Mod1</td>
<td>Mod2</td>
</tr>
<tr>
<td>Final log likelihood</td>
<td>-522.7601</td>
<td>-522.76</td>
</tr>
<tr>
<td>Rho-square</td>
<td>0.188</td>
<td>0.188</td>
</tr>
<tr>
<td>Adjusted Rho-square</td>
<td>0.134</td>
<td>0.138</td>
</tr>
<tr>
<td>AIC</td>
<td>1115.52</td>
<td>1109.52</td>
</tr>
<tr>
<td>BIC</td>
<td>1255.221</td>
<td>1237.247</td>
</tr>
</tbody>
</table>
The goal was to obtain industry preference towards autonomous trucks.
We designed a survey to capture preference based on number of variables.
Obtained a reasonable data for modeling and analysis.
  - Sample size can certainly be improved as a part of future work.
Survey data itself is insightful.
Modeling approach provided us likelihood of adoption cross classified by
  - Age
  - Education
  - Type of fleet owner
  - Geographic Level
  - Tenure at work
  - Many other findings we did not discuss because of time limitation.
Other Highly automated technologies - Industry Adoption

Platooning technology (source: oemofhighway.com)
Automated transit buses (source: olli.com)
Drones for last mile deliveries (source: dhl.com)
3-D printing technology (source: cnn.com)
RSU (source: dot.gov)
Preliminary work

- Methodological groundwork for predicting the adoption rate of innovations by organizations.
- By incorporating peer effects, we provide an estimate of the market penetration rate of vehicle innovations.
- This research can help policymakers to prepare appropriate legislation and regulations for CAV operations.
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  – Dr. Mihalis Golias (UofM)
  – Dr. Miguel Figliozzi (PSU)
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