Accommodating variation in driving patterns between and within households

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To accurately estimate PHEV energy use, driving pattern variations between and within households are significant and can be properly handled.

- **PHEV**
  - A vehicle with electric range (R_0 in miles) and easily accessible fuel
- **Energy use**
  - Average elec use (E in kWh/mile) and avg fuel use (F in gge/mile)
  - Average over vehicle lifetime. For either fleet or individual
- **Driving pattern**
  - Characterized by X_{hd}, the driving distance of the PHEV by household *h* during day *d*. HH h1's driving pattern = $\{X_{h1d} : \forall\, d\}$
  - Variation between households ← $\{X_{h1d} : \forall\, d\} \neq \{X_{h2d} : \forall\, d\}$
  - Variation within HH ← $X_{h1d1} \neq X_{h1d2}$
- **Significant**
  - Assuming $X_{hd} = const, \forall\, d, h$ → significant bias in est. of E and/or F
- **Properly handled**
  - Significantly reduce the estimate bias; simple; low data requirements

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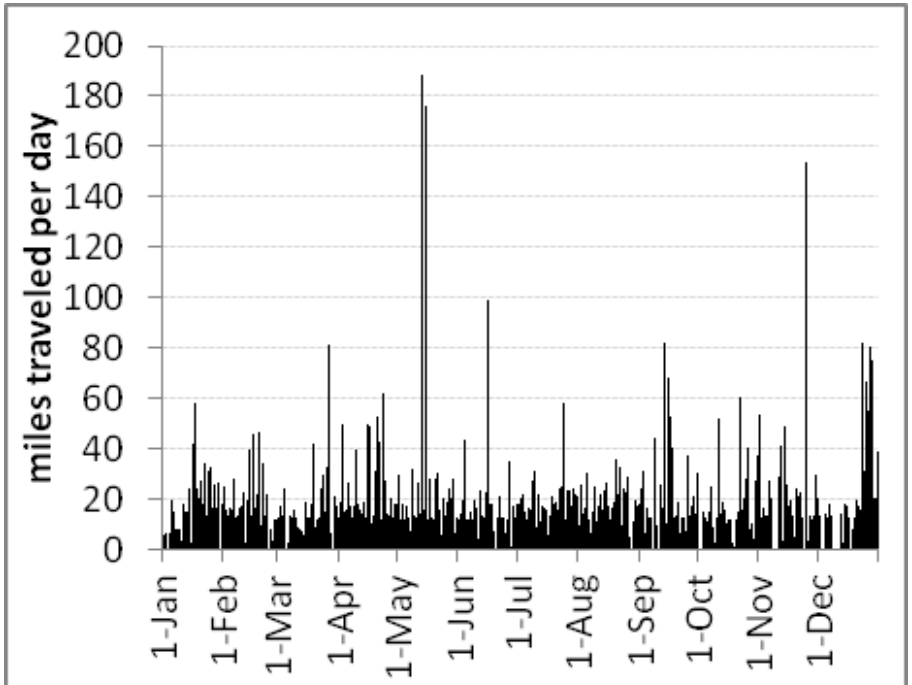
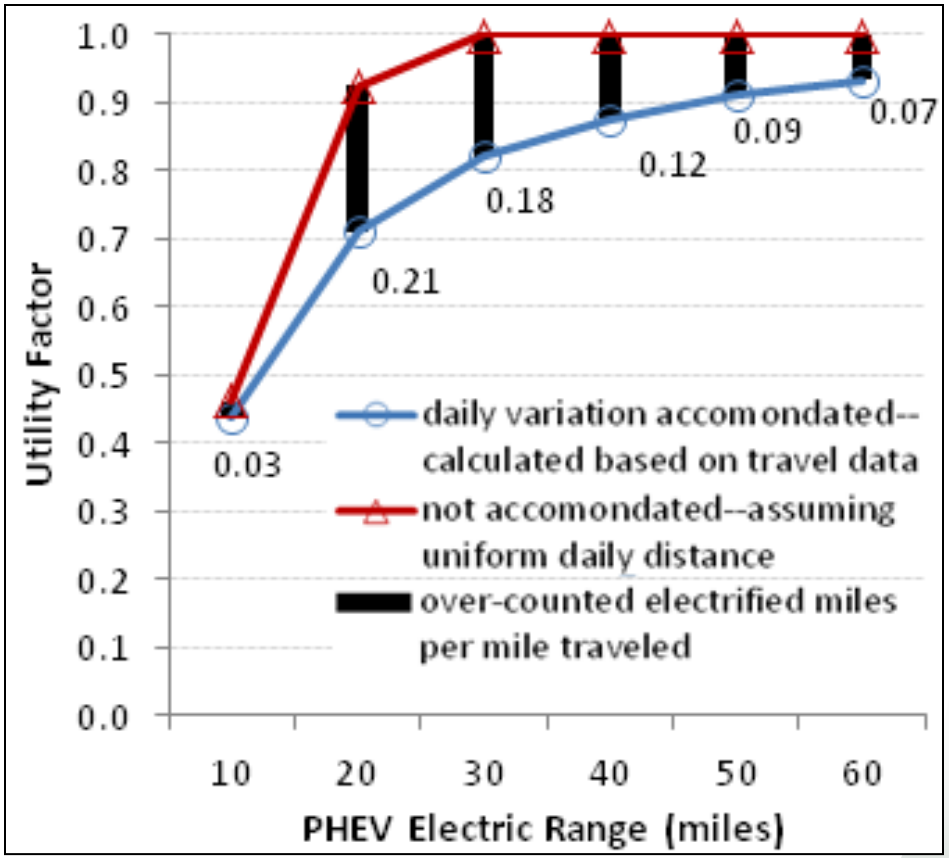
Uniform daily VMT approximation (UDVA) over-counts e-distance and under-counts fuel use.



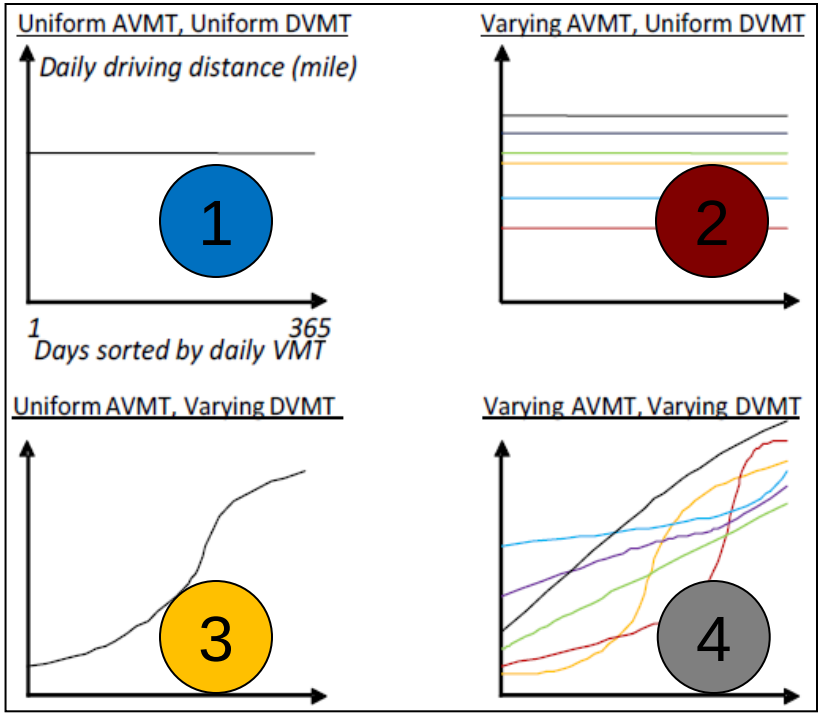
Note: daily distances of a Seattle driver during 2005, N= 348, avg=21.6 miles (source: PSRC)

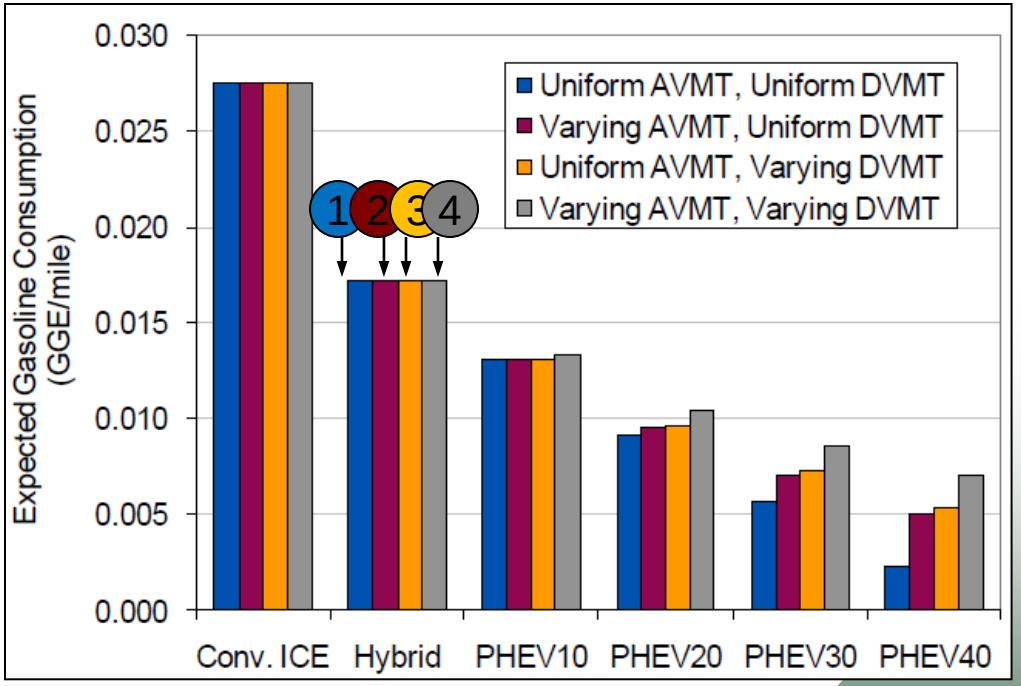


- Also, max bias seems to occur when R_{cd} approaches X_{avg} = 21.6 miles
- But can these observations be generalized?

UDVA leads to ~70% under-est. of petro. use of PHEV40 for US drivers; ~25% if either btw-HH or within-HH variation is captured

- **Based on the ORNL Gamma method applied to 3775 sample drivers from NHTS 2001**
  - Lin & Greene(2011), TRR, DOI:10.3141/2252-13





Various approaches exist and learn from each other. Personal UF vs. fleet UF—different context.

- **Data-based—accurate but costly, not flexible**
  - Cross-sectional data (e.g. NHTS) (for btw-HH variation)
    - E.g. SAE J2841, but treating NHTS as like time-series?
    - ORNL, ANL, NREL, UC Davis, UW Madison, EPRI, etc.
  - Time-series data (for within-HH variation)
    - ORNL, NREL
  - Panel data (for both variations)
    - ORNL, INL, Georgia Tech, UC Davis, BRW, etc.
    - Many city/regional panel data exist, but national panel data is lacking
- **Functional approximation—flexible, simple, but need validation**
  - chi-squared, 1 parameter, (U Michigan)
  - **Gamma**, 2 parameter (ORNL)
  - Weibull, 2 parameter (ORNL, Carnegie Mellon U)
  - Lognormal, 2 parameter (ORNL, ISI Germany)
  - composite distribution, 5 parameter (Ford)

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ORNL has proposed, formulated, compared, validated, and applied the Gamma method, which aims at both accuracy and simplicity.

- **1st to assume Gamma distribution for daily driving distance**
  - Greene (1985, TR-B)
- **Formulate PHEV energy use based on X_{hd}~Gamma(k,θ)**
  - Lin & Greene (2011, TRR)
- **Compare Gamma, Weibull, and Lognormal; validate Gamma**
  - Lin, Dong, Liu & Greene (2012, TRR)
  - compares Gamma, Weibull, and Lognormal; validated Gamma with GPS panel data (183 vehicles; each continuously tracked for at least 6 months)
- **Application examples**
  - Consumer choice model MA3T
  - National average UF
  - ORNL PHEV Calculator

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Gamma distribution can be specified by the mean and mode, i.e. average and typical daily distances

- **Expected daily fuel use (gge/day)**

$$E_g = C_{g,cd} \cdot \int_0^{R_{cd}} x \cdot p(x) \cdot dx + C_{g,cs} \cdot \int_{R_{cd}}^{M} x \cdot p(x) \cdot dx + (C_{g,cd} - C_{g,cs}) \cdot R_{cd} \cdot (1 - \int_0^{R_{cd}} p(x) \cdot dx)$$

- **Expected daily electricity use (kWh/day)**

$$E_e = C_{e,cd} \cdot \left(\int_0^{R_{cd}} x \cdot p(x) \cdot dx + R_{cd} \cdot (1 - \int_0^{R_{cd}} p(x) \cdot dx) \right)$$

- **Gamma distribution of daily distance**

$$p(x;k,\theta) = x^{k-1} \frac{e^{-x/\theta}}{\theta^k \Gamma(k)}, \qquad k\theta = x_{avg}, \qquad (k-1)\theta = x_{md}$$

References:

Lin, Z., & Greene, D. L. (2011). Assessing Energy Impact of Plug-In Hybrid Electric Vehicles: Significance of Daily Distance Variation over Time and Among Drivers. *Transportation Research Record, 2252*(1), 99-106.

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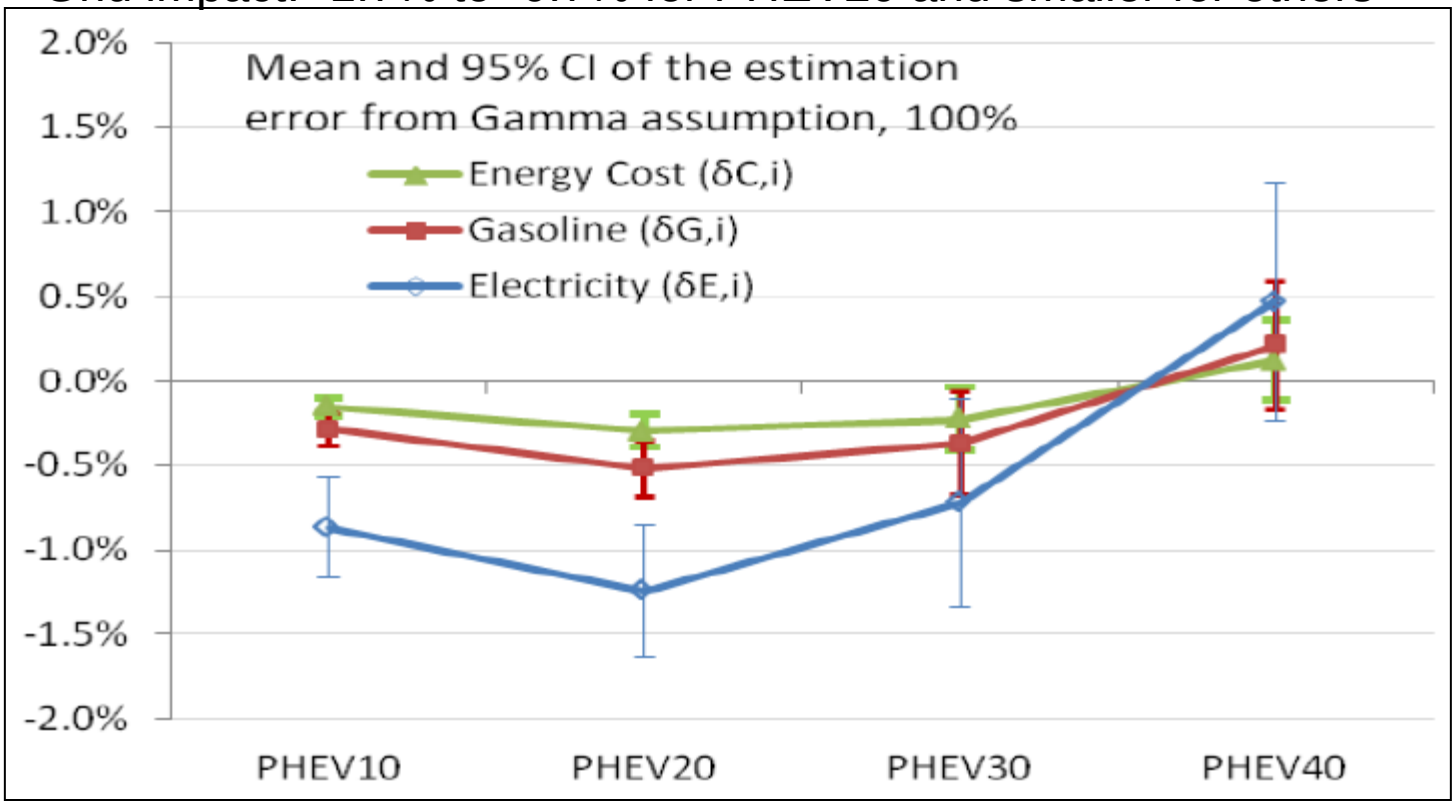
For PHEV fleets, Gamma method yields highly accurate estimates, relative to data-based estimates

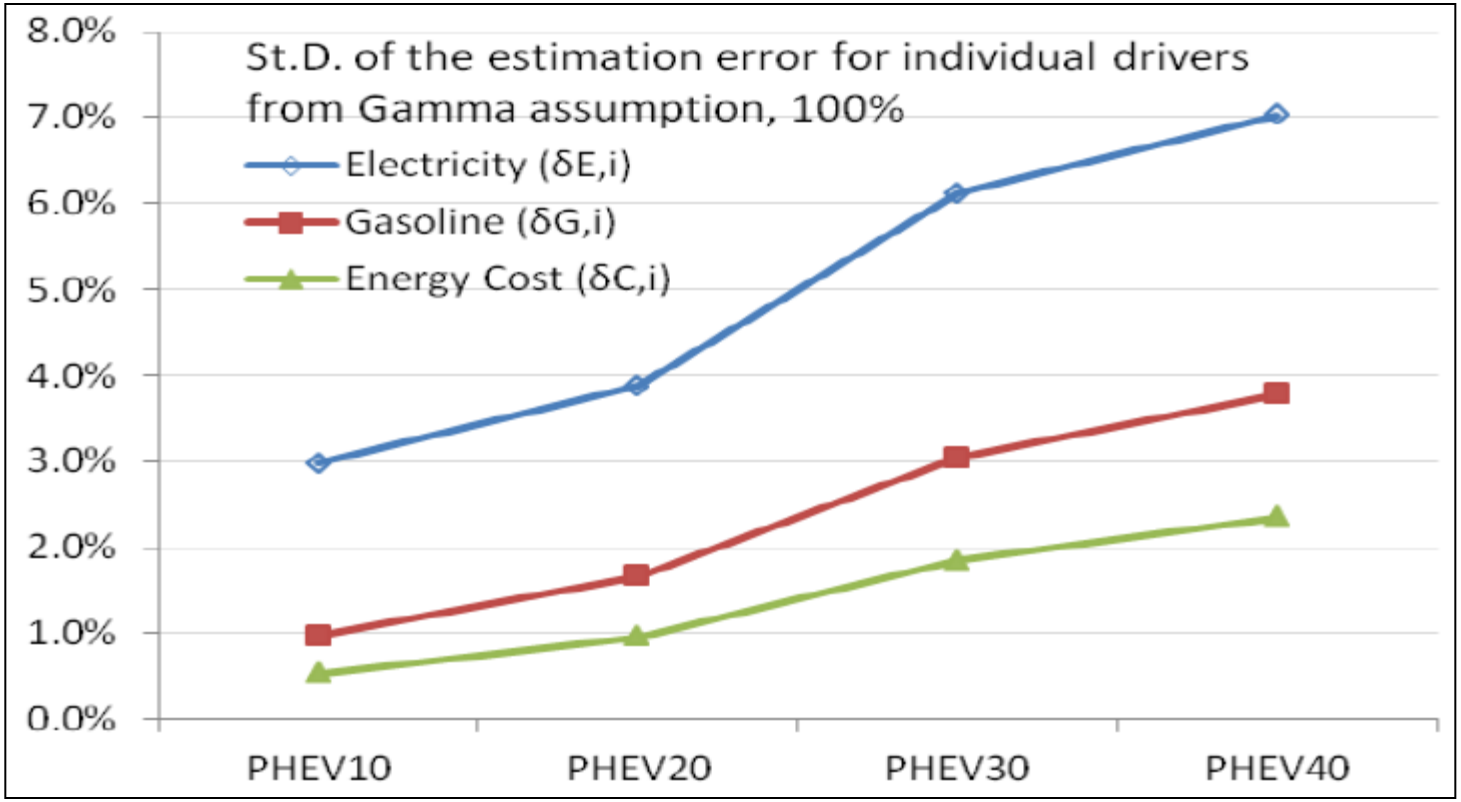
- **Error magnitude**
  - Oil savings: -0.7% to -0.3% for PHEV20 and smaller for others
  - Grid impact: -1.7% to -0.7% for PHEV20 and smaller for others



Lin, Z., Dong, J., Liu, C., & Greene, D. (2012). Estimation of Energy Use by Plug-In Hybrid Electric Vehicles: Validating Gamma Distribution for Representing Random Daily Driving Distance *Transportation Research Record, 2287*(1), 37-43.

Gamma method is also reliable for estimating individual PHEV energy cost

- **Energy cost error**
  - St.d. range from 0.5% for PHEV20 to 2.3% for PHEV40



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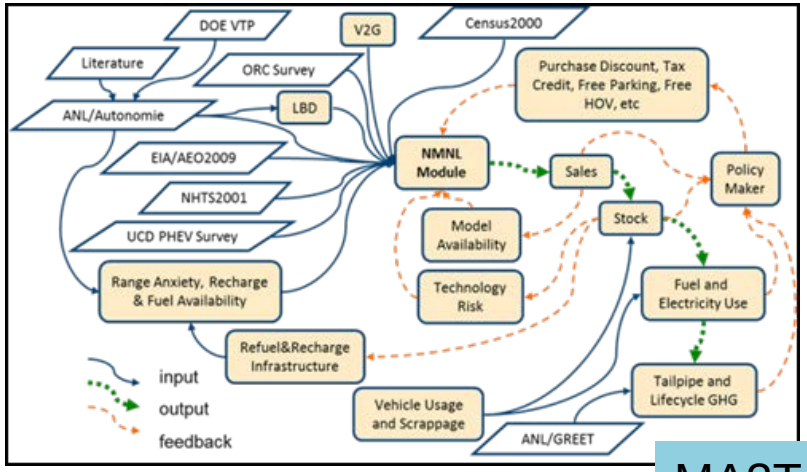
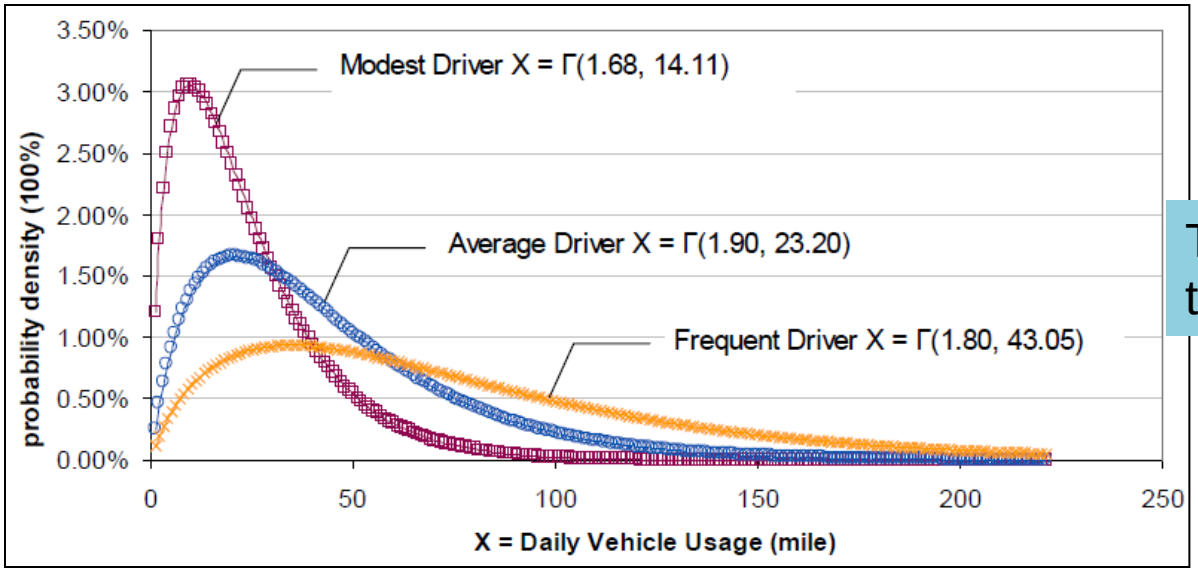
Target driver population clustered into driver groups, each described by market share and a distinct Gamma distribution, calibrated to data

- Three driver types—Modest, Average, and Frequent drivers; distributions calibrated to NHTS 2001
- Shares of each driver types varies by census division and residential area
- Implemented in ORNL MA3T model

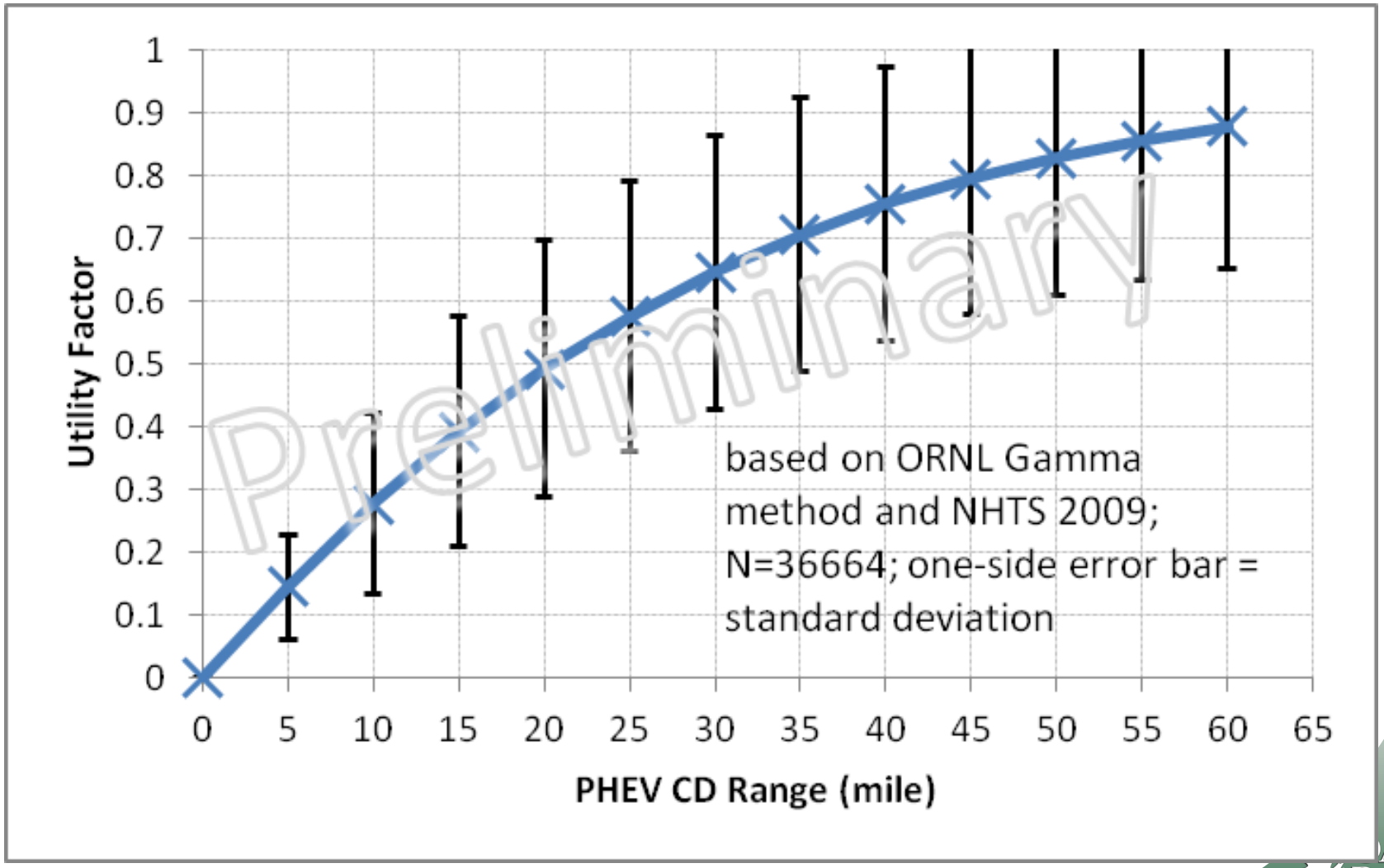


MA3T

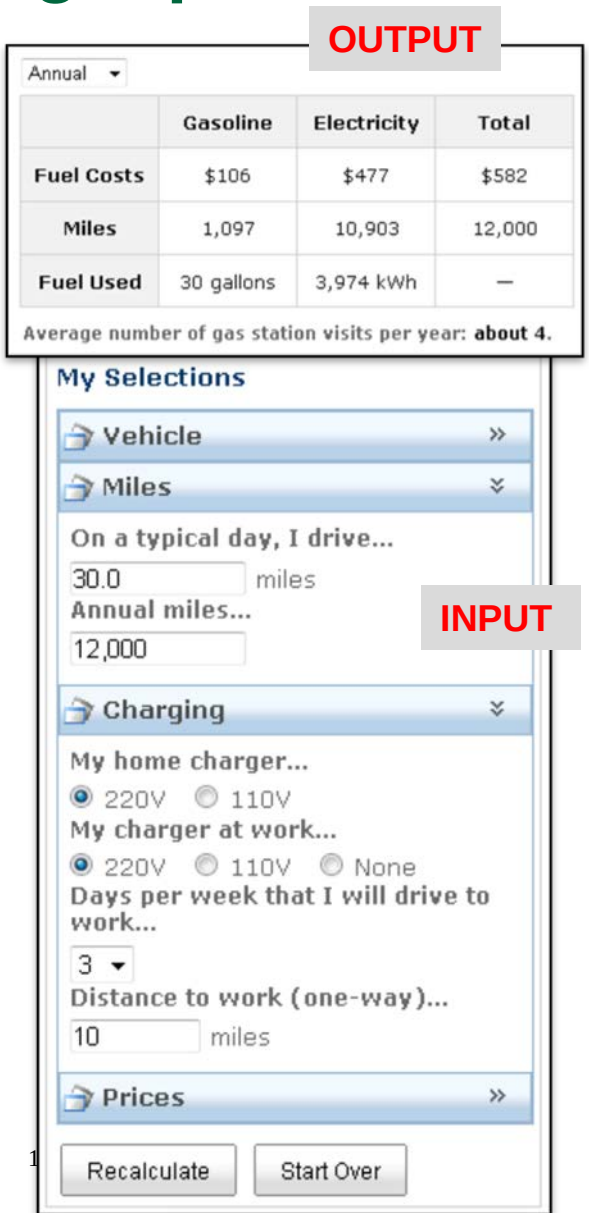


Three driver types in MA3T

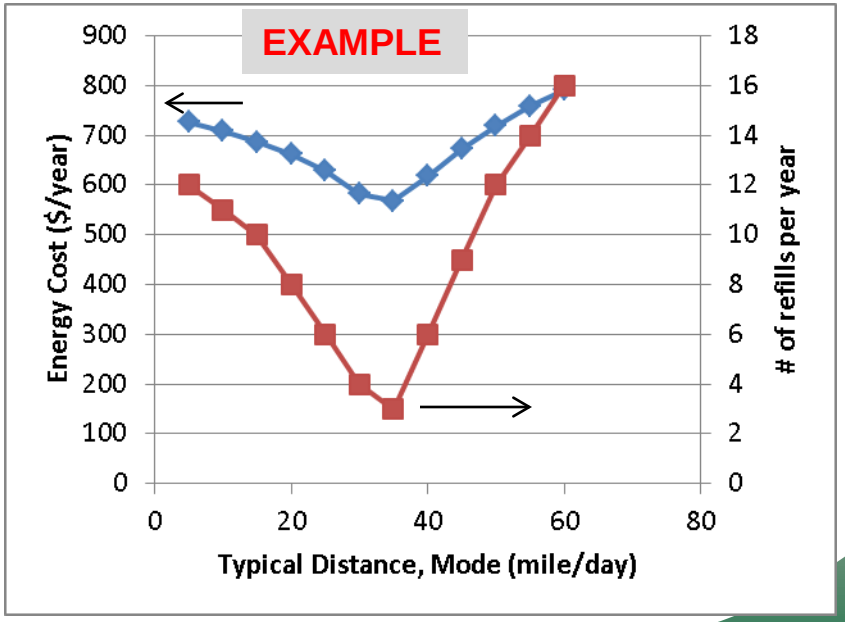
National PHEV UF estimated by applying ORNL Gamma method to NHTS 2009 data, reflecting btw-&within-HH variations without using panel data



ORNL PHEV Calculator—answer simple questions, get personalized estimates for your PHEV



- **Sensitivity of PHEV cost-benefits to**
  - Vehicle make and model
  - Annual distance and typical daily distance
  - Home charger type
  - Work charger type, commuting days and distance
  - Fuel and electricity prices



Btw-&within-HH variations are important factors for PHEV energy use estimation. With accuracy validated, ORNL Gamma method is a simple and flexible alternative to costly panel data.

- **Uniform daily VMT approximation**
  - Graphical and math proof of the e-mile-overcounting bias
  - Shown significance of the bias with empirical results
- **Review of studied approaches to accommodating both between- and within-household variations**
- **Introduce the ORNL Gamma method—formulation, comparison, validation, and 3 applications**
  - MA3T consumer choice model
  - National UF curve—average and variation
  - ORNL PHEV Calculator

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THANK YOU