Disentangling Vehicle Technology & Self-Selection Effects on Household Alternative Fuel Vehicle Use –

A Tri-variate Copula Based Endogenous Regime Switching Framework

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U.S. DEPARTMENT OF ENERGY

THE UNIVERSITY OF TENNESSEE KNOXVILLE

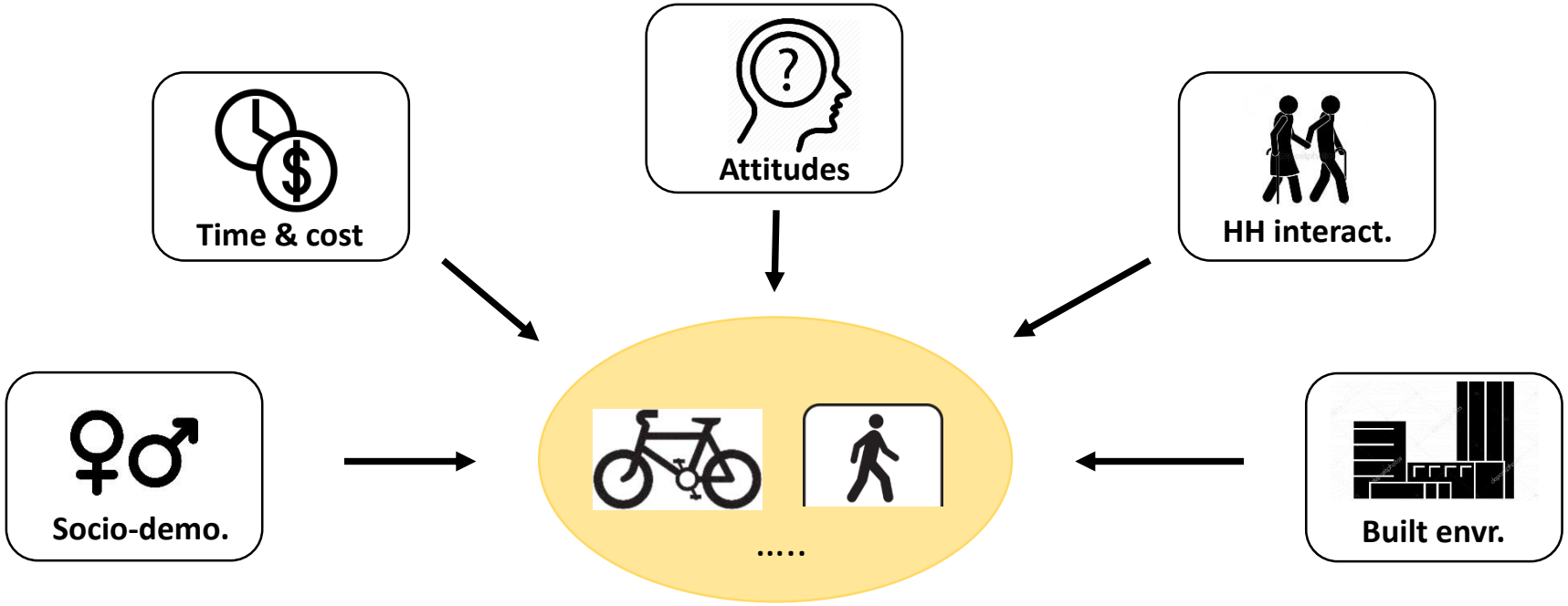
OAK RIDGE National Laboratory

DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

Travel Behavior

"Zones don't travel; people travel!"
Slogan, Travel Demand Forecasting Project, 1972

Conceptual Framework



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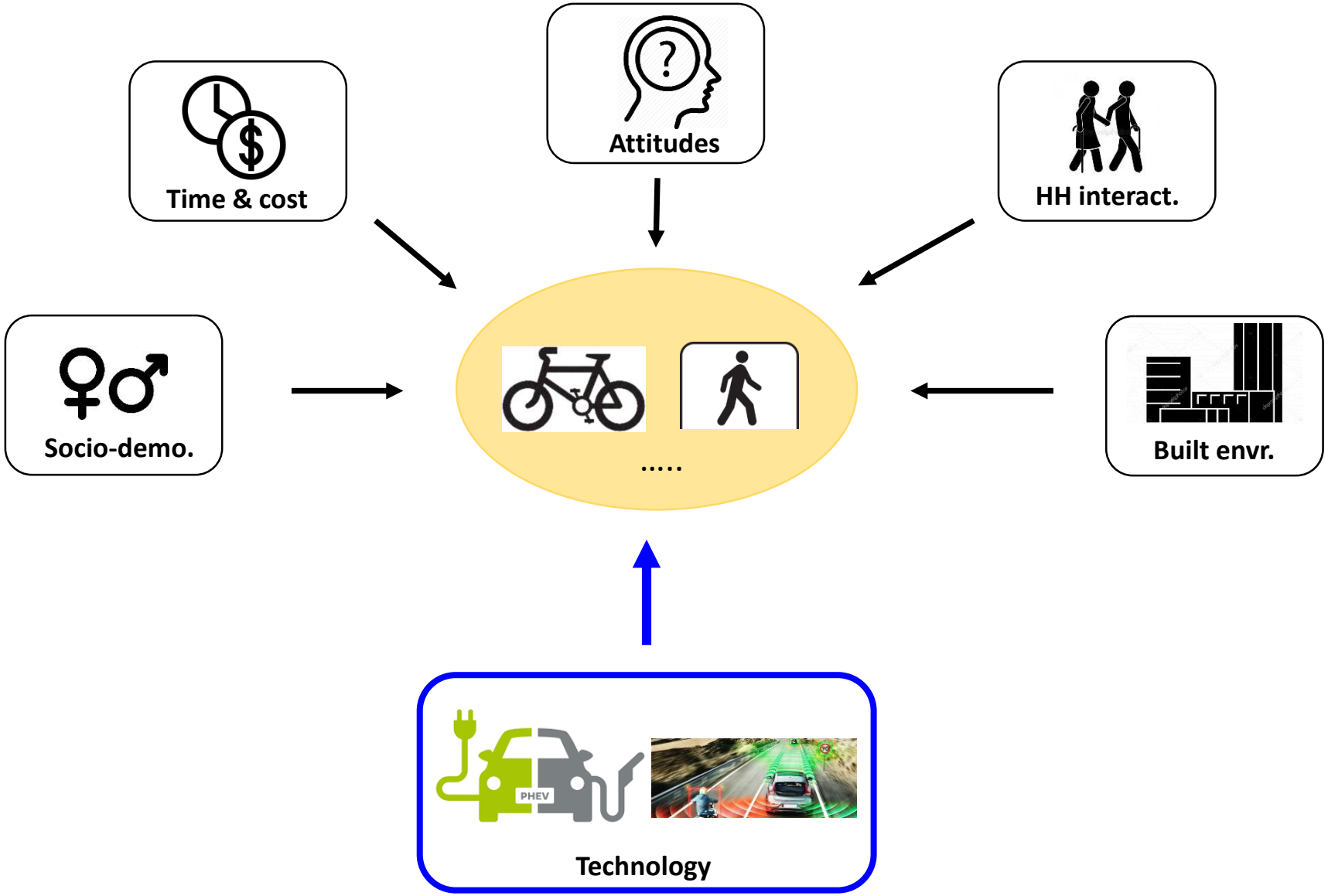
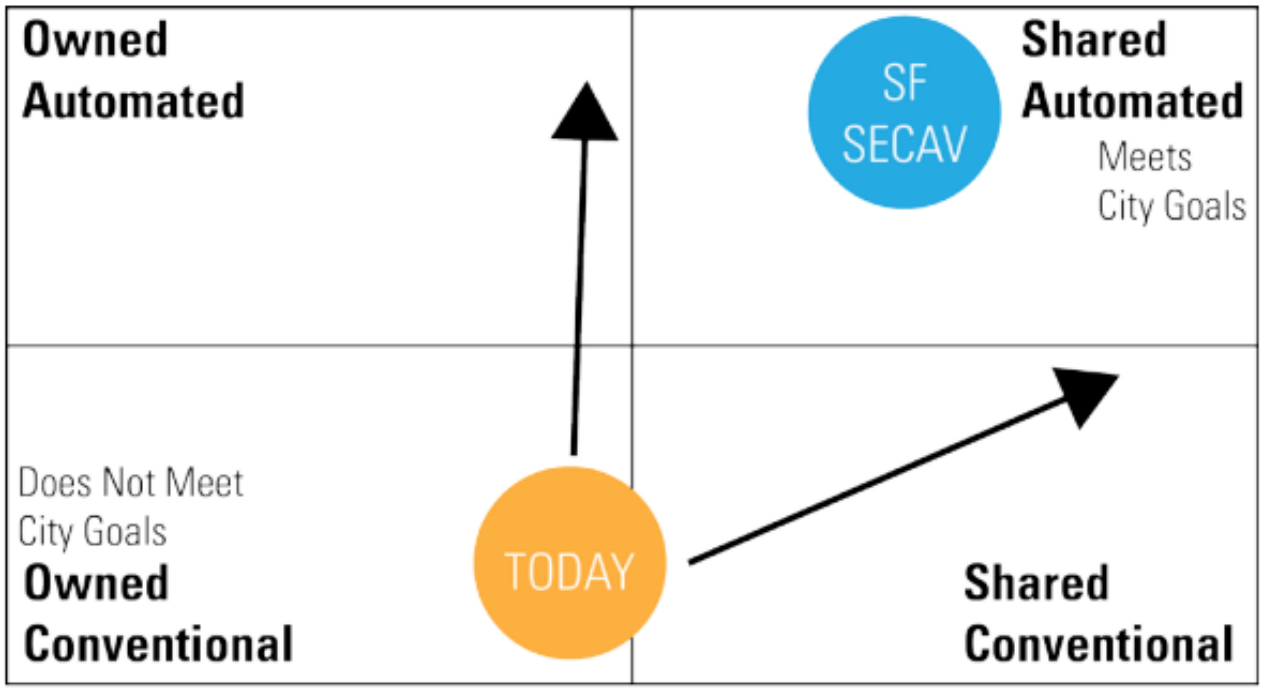


Emerging Transportation Paths (SECAV)



Ownership Model

1.0 Internal Combustion Engine/Pedal Power

2.0 Electric Vehicles

3.0 Electric Driverless Vehicles

Shared Model

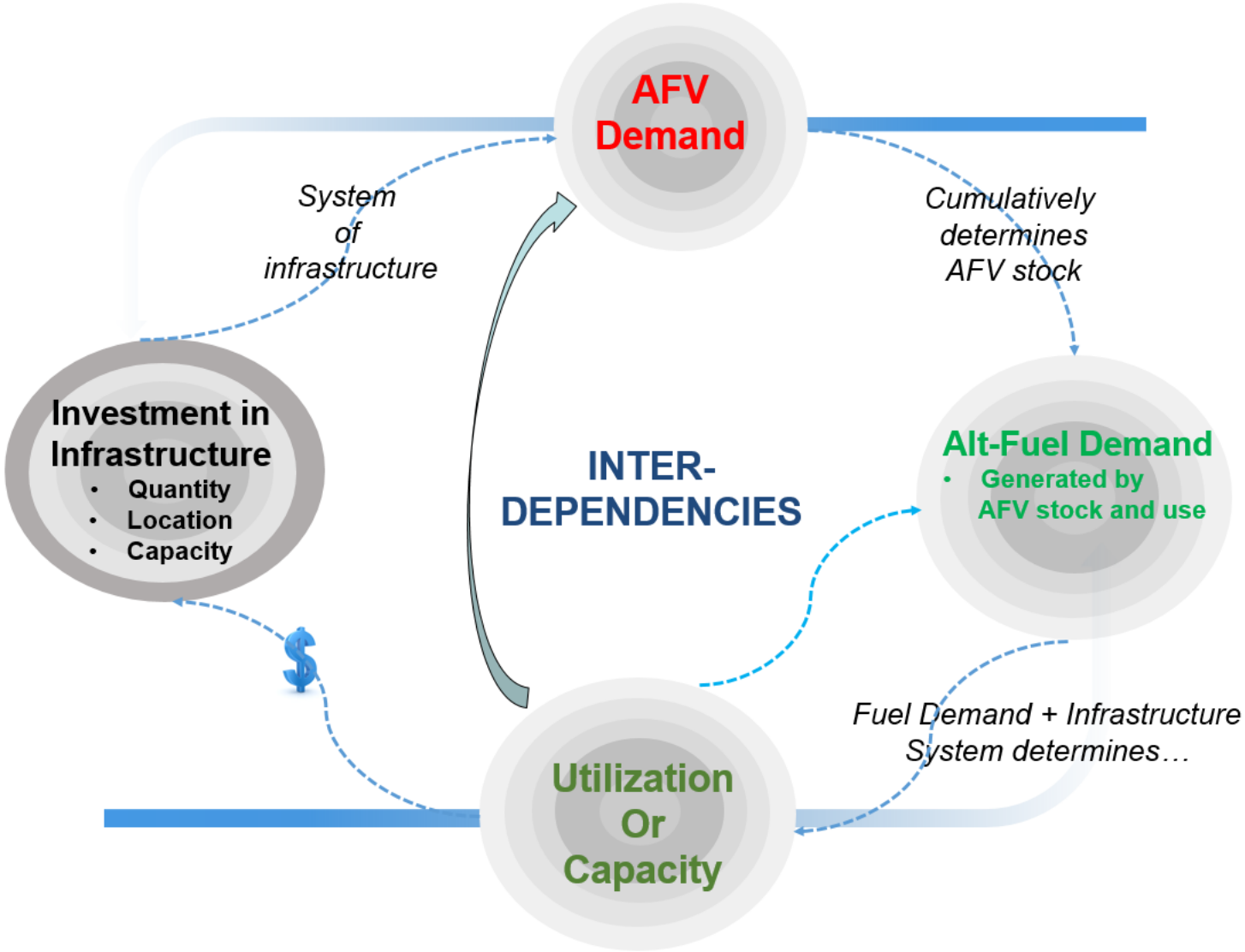
1.0 Shared Vehicles

2.0 Electric Shared Vehicles

3.0 Shared, Electric, Connected, Automated Vehicles (SECAV)

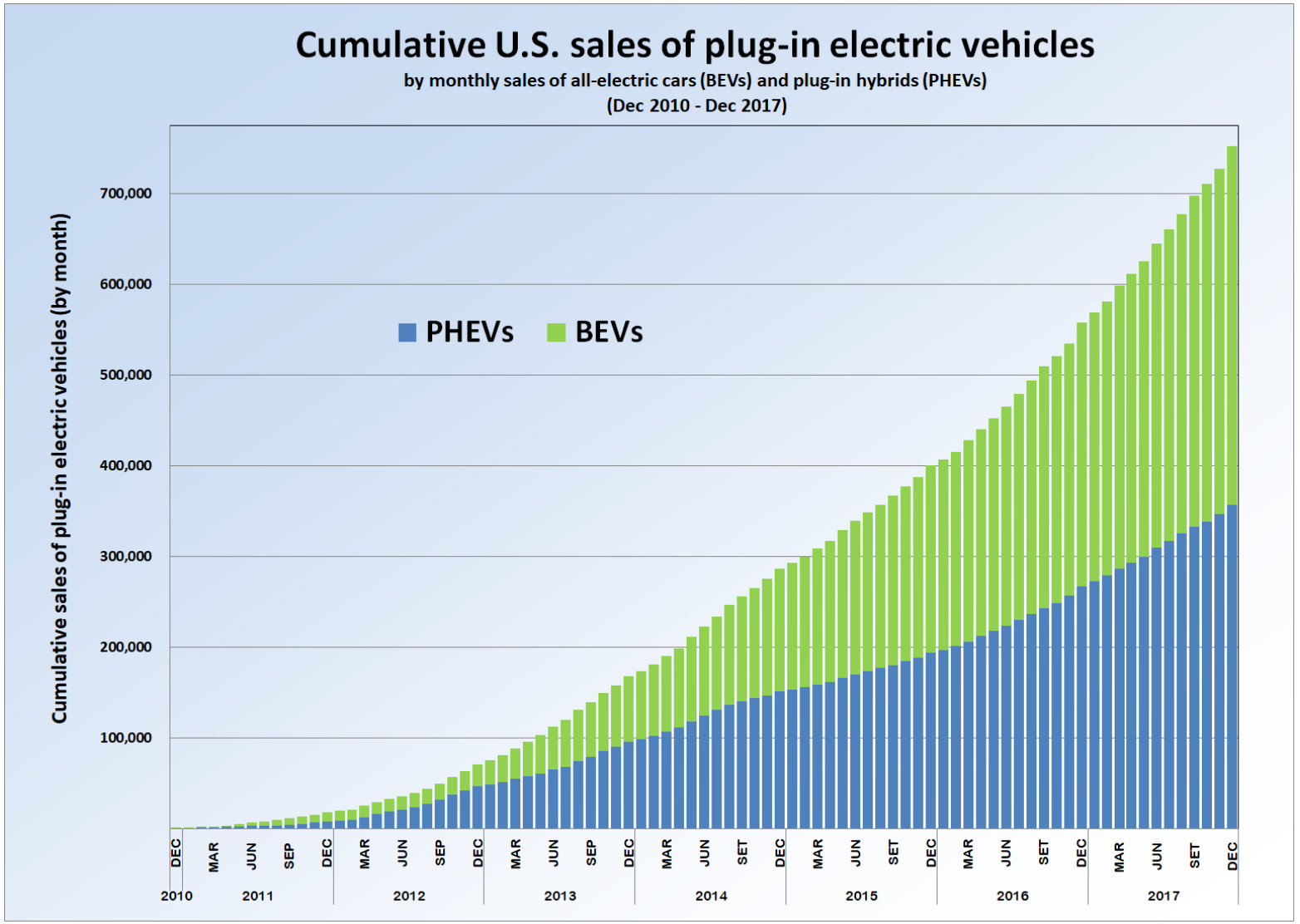
Source: Smart City Challenge: San Francisco Vision Statement

Bigger Picture – The Green Mobility of Future



Greene, Khattak, & Wali (2017)

Advancement of fuel tech - Trends in the U.S.



Source: https://www.hybridcars.com/may-2018-sales-dashboard/

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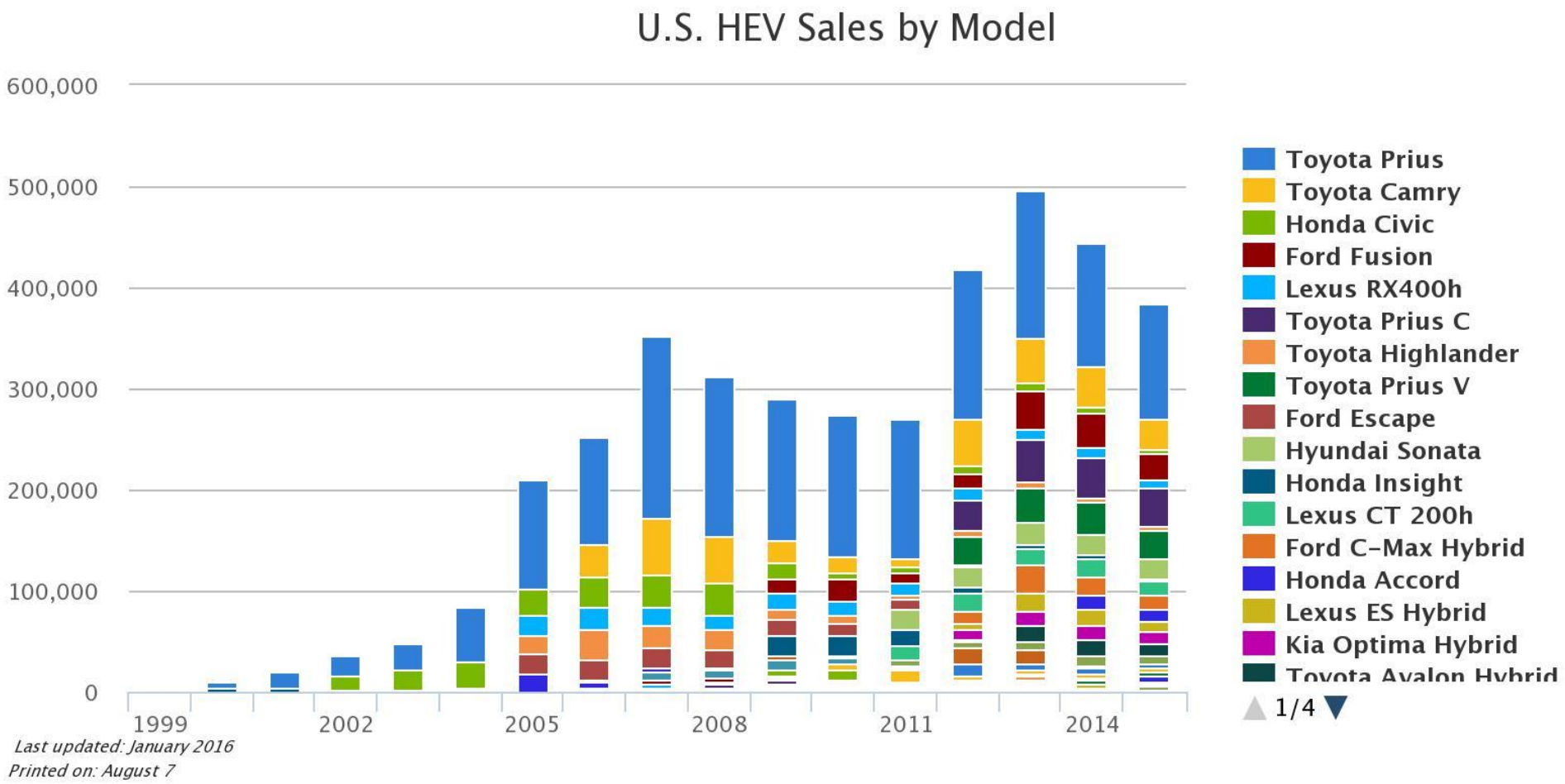
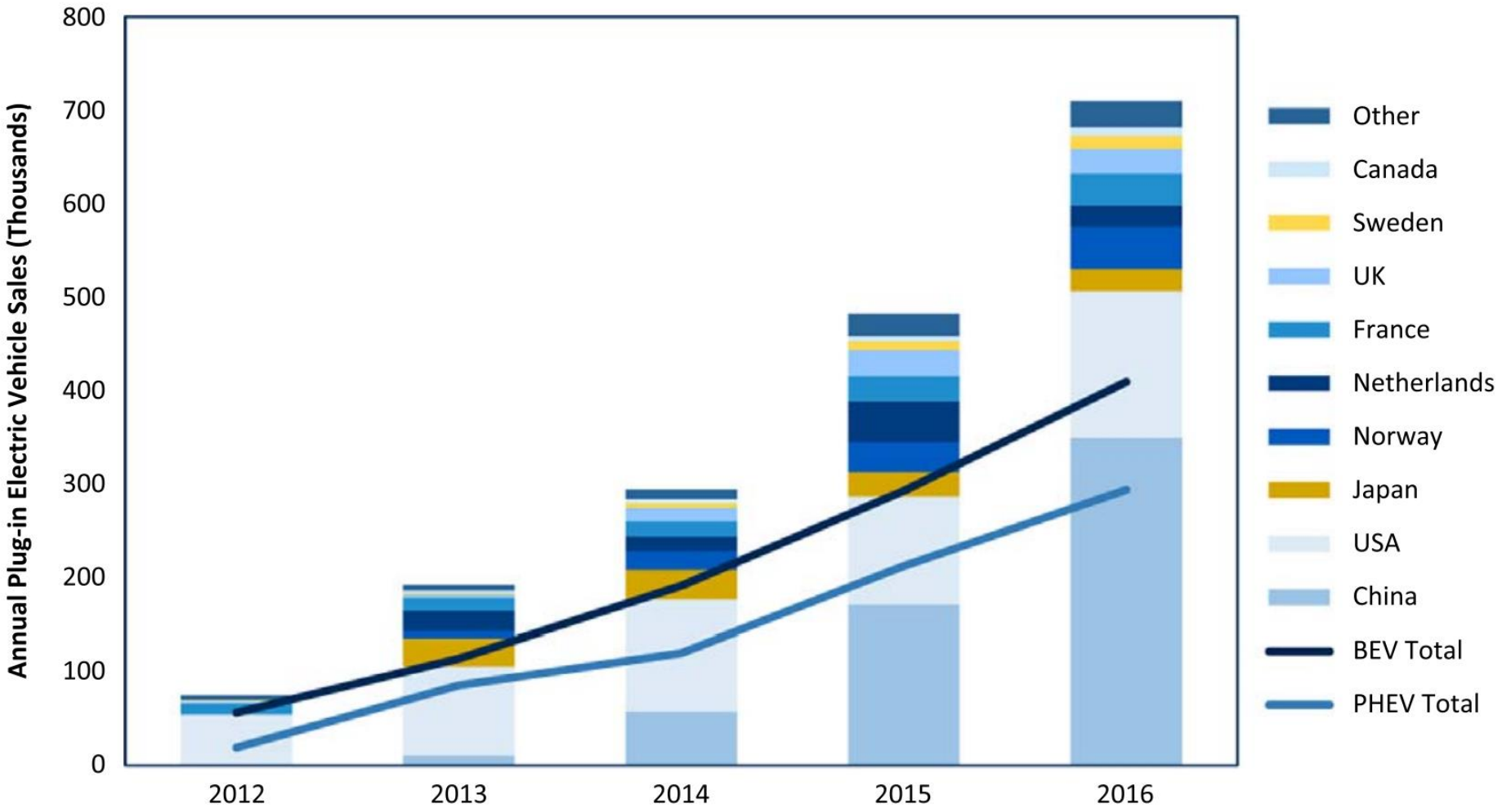


Source: https://www.afdc.energy.gov/data/10301

Advancement of fuel tech – Global Trends



Source: Hardman, Chandan, Tal, and Turrentine (2017)

Key Questions

- Mechanisms/factors leading to households purchasing AFVs (plug-in electric /plug-in hybrid vehicles)?

- Vehicle use patterns of AFV households, compared to non-AFV counterparts?

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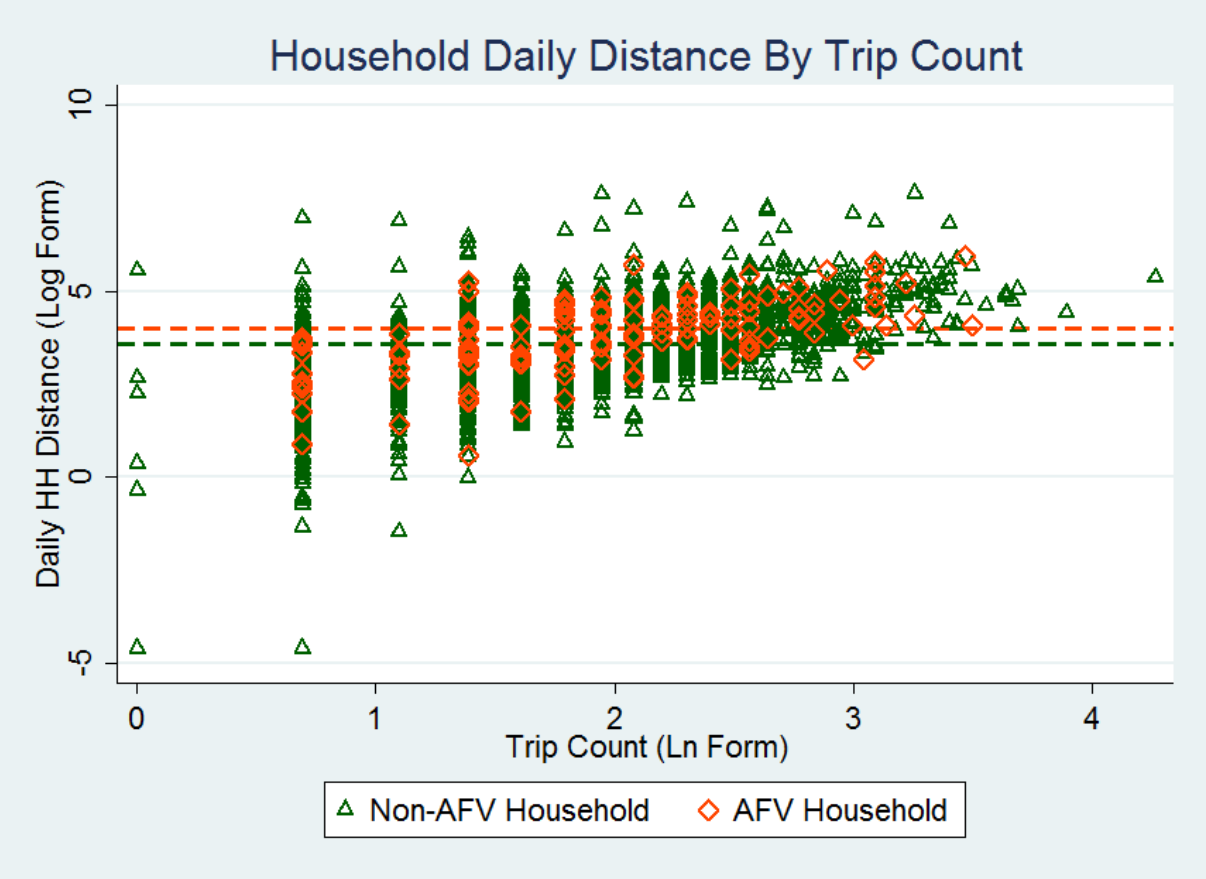
- Vehicle use patterns of AFV households, compared to non-AFV counterparts?

- Role of “self-selection” & “true” vehicle technology effects?

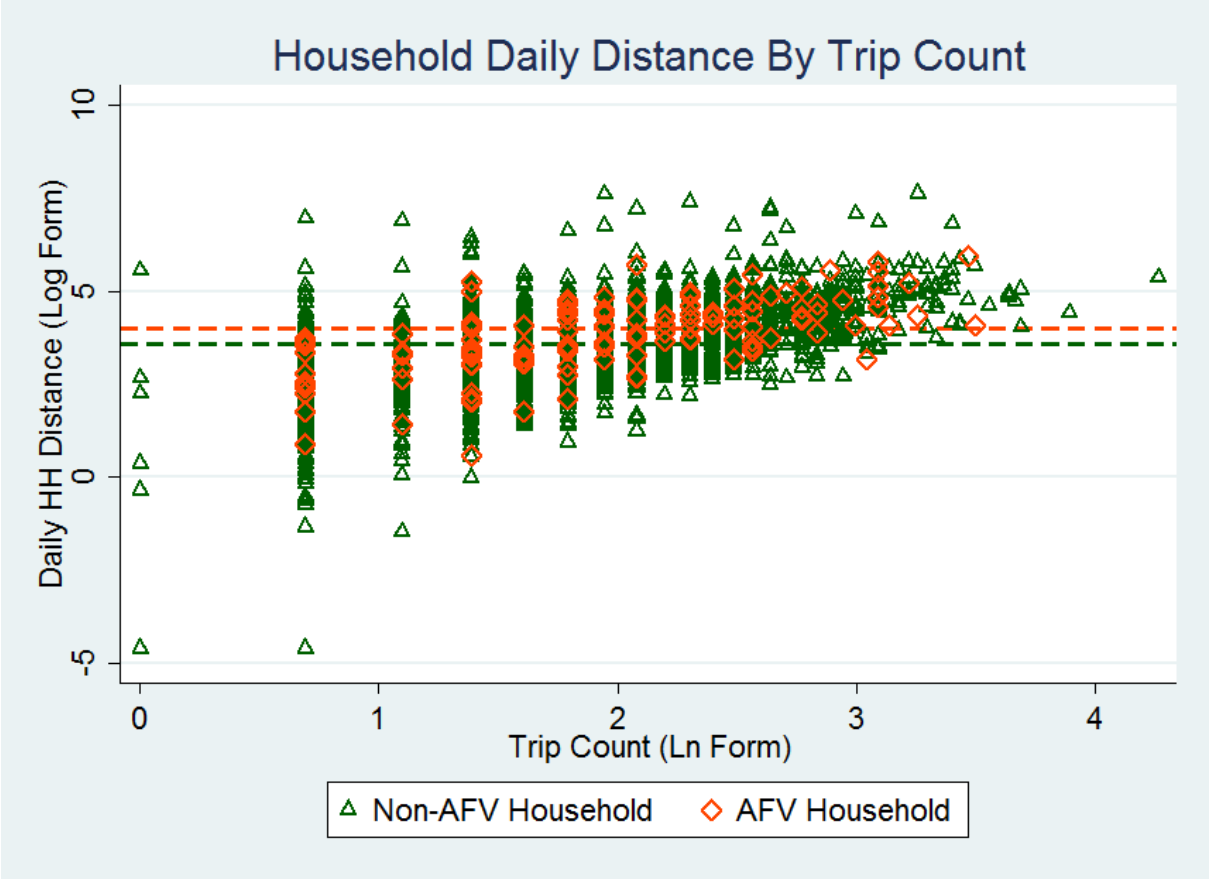
Developing Intuition



Orange Line: Mean Daily Distance by AFV HH

Green Line: Mean Daily Distance by Non-AFV HH

Developing Intuition



Feature of the Data (example)

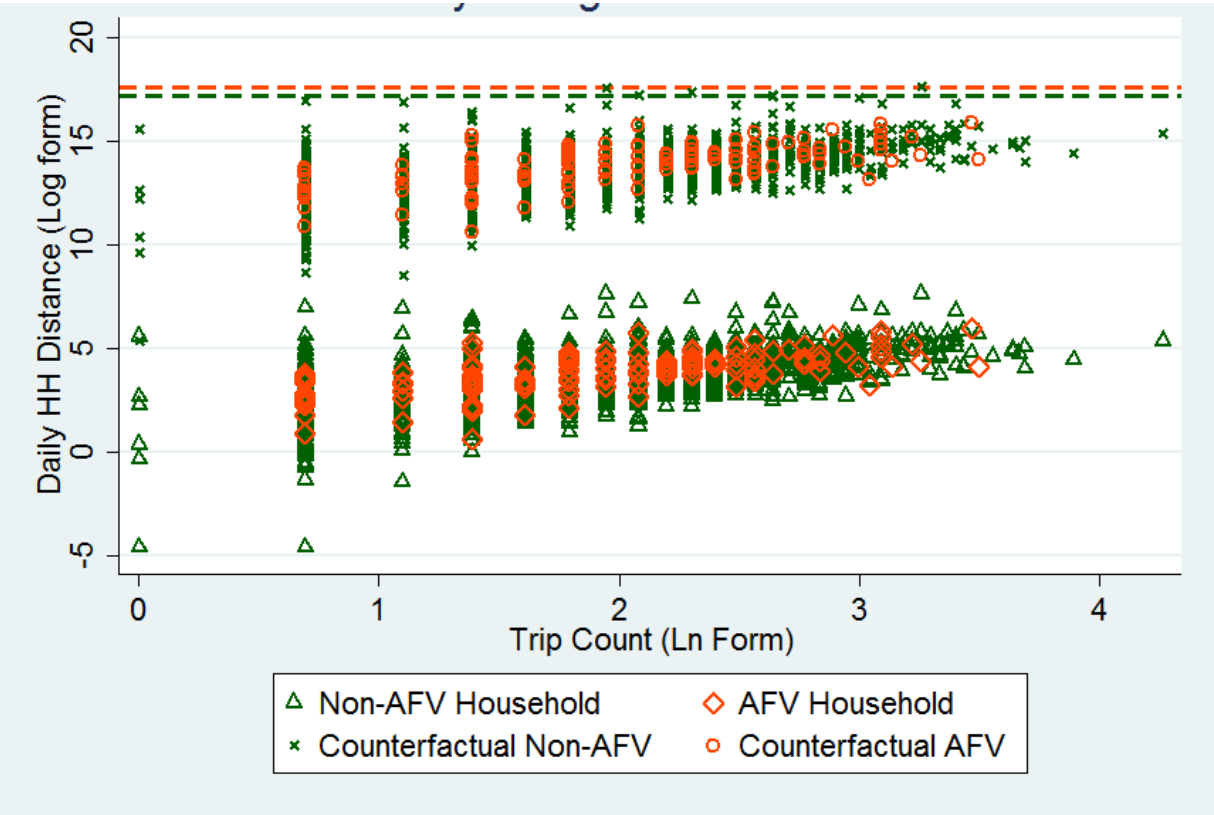
- Avg. AFV Distance = 4 log-miles
- Avg. Non-AFV Distance = 3.58 log-miles

Question: Can we conclude that AFV Households travel more?

Orange Line: Mean Daily Distance by AFV HH

Green Line: Mean Daily Distance by Non-AFV HH

Having counterfactuals?



Feature of the Data (example)

- Avg. AFV Distance = 17.63 log-miles
- Avg. Non-AFV Distance = 17.16 log-miles

We could have concluded if we had countermeasures…

Orange Line: AFV (Treated) Mean

Green Line: Non-AFV (Untreated) Mean

Methodological Challenges

- Observational Data (AFV/Non-AFV Households)
- Defining characteristic: **Not *randomized***
- Self-selection bias (Khattak & Rodriguez, 2005; Fan & Khattak, 2009)
- Endogeneity bias (Bhat, 1997; Bhat & Koppelman, 1993; Bhat & Eluru, 2009)

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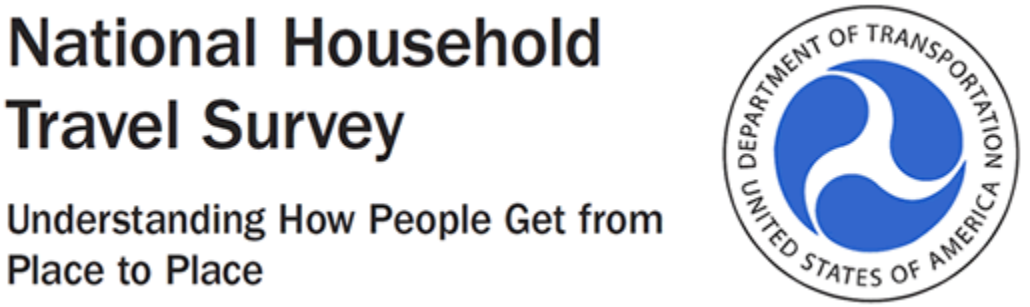
Quantify the true ***"causal effect"*** when the selection into being an AFV vs Non-AFV HH is presumably endogenous?

Empirical Context

- 2017 National Household Travel Survey



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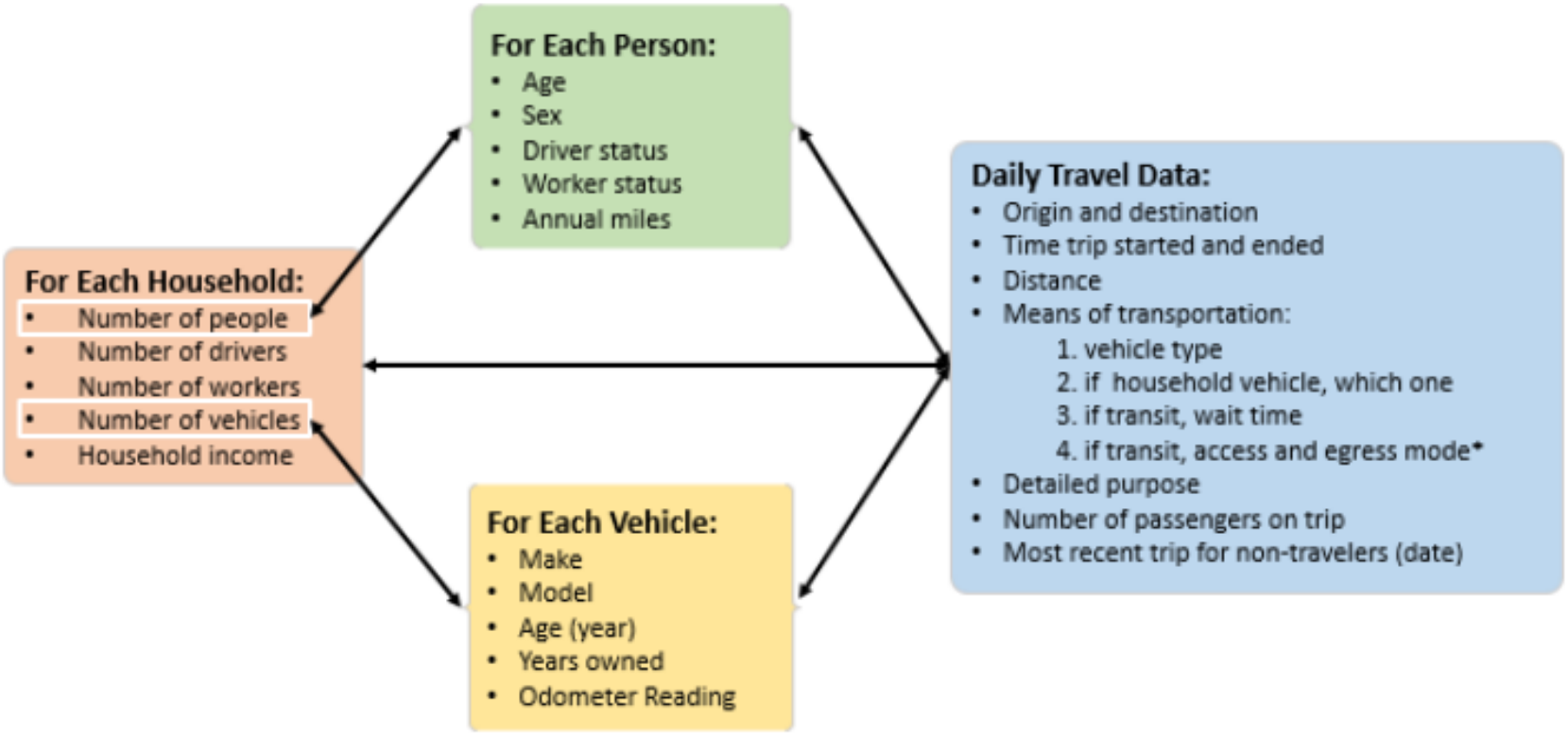
National Household Travel Survey

Understanding How People Get from Place to Place



Source: NHTS 2017 User Guide

Data Structure

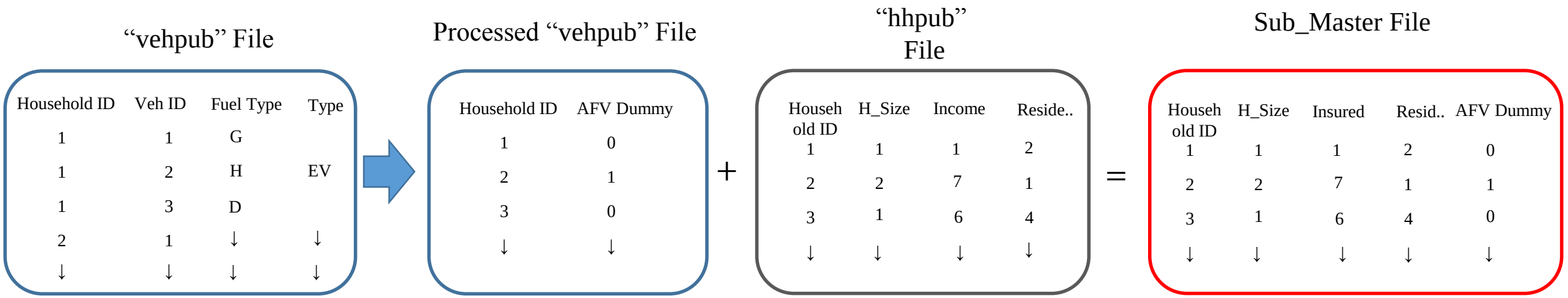
"vehpub" File

Household ID	Veh ID	Fuel Type	Type
1	1	G	
1	2	H	EV
1	3	D	
2	1	↓	↓
↓	↓	↓	↓

Processed "vehpub" File

Household ID	AFV Dummy
1	0
2	1
3	0
↓	↓

Data Structure



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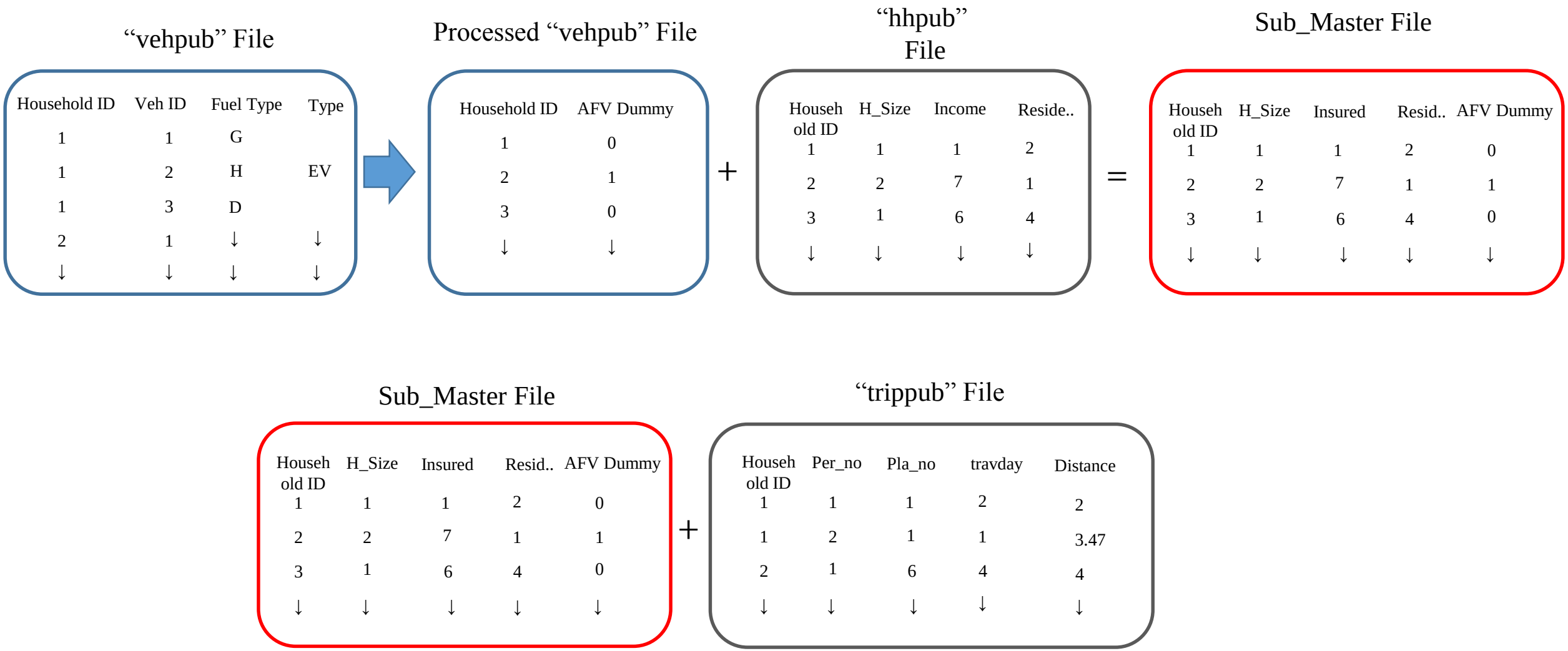

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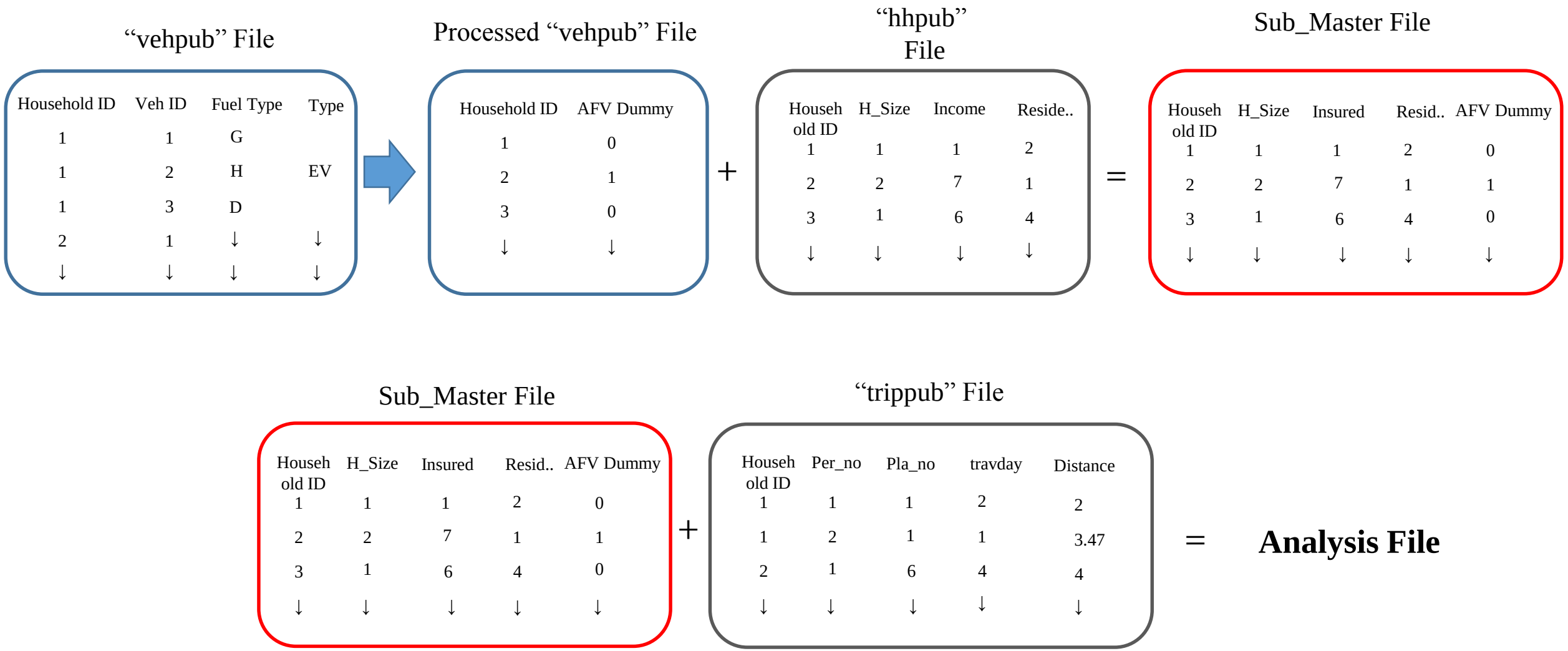
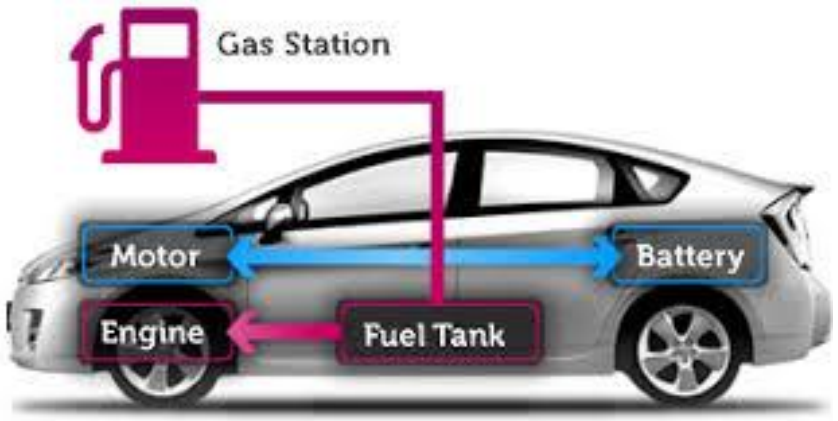


Definitions Used in this Study



Non Plug-in Hybrid Household

Household having "at-least" one **non plug-in hybrid vehicle**

Plug-in Hybrid/Electric Veh Household

Household having "at-least" one **plug-in hybrid/electric vehicle**

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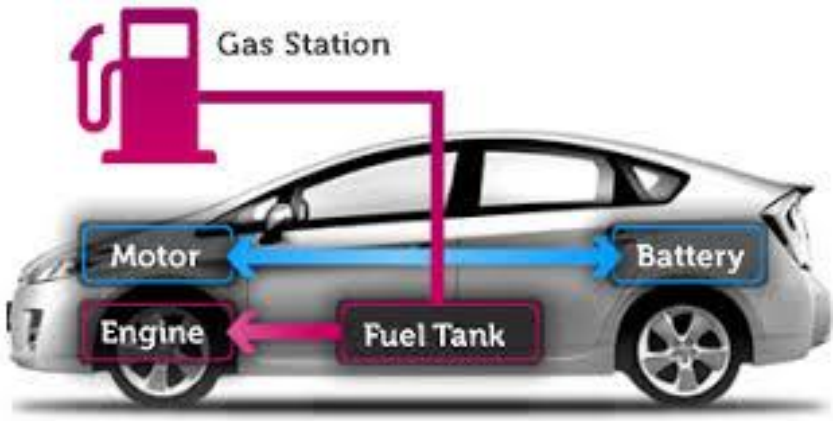

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Plug-in Hybrid/Electric Veh Household

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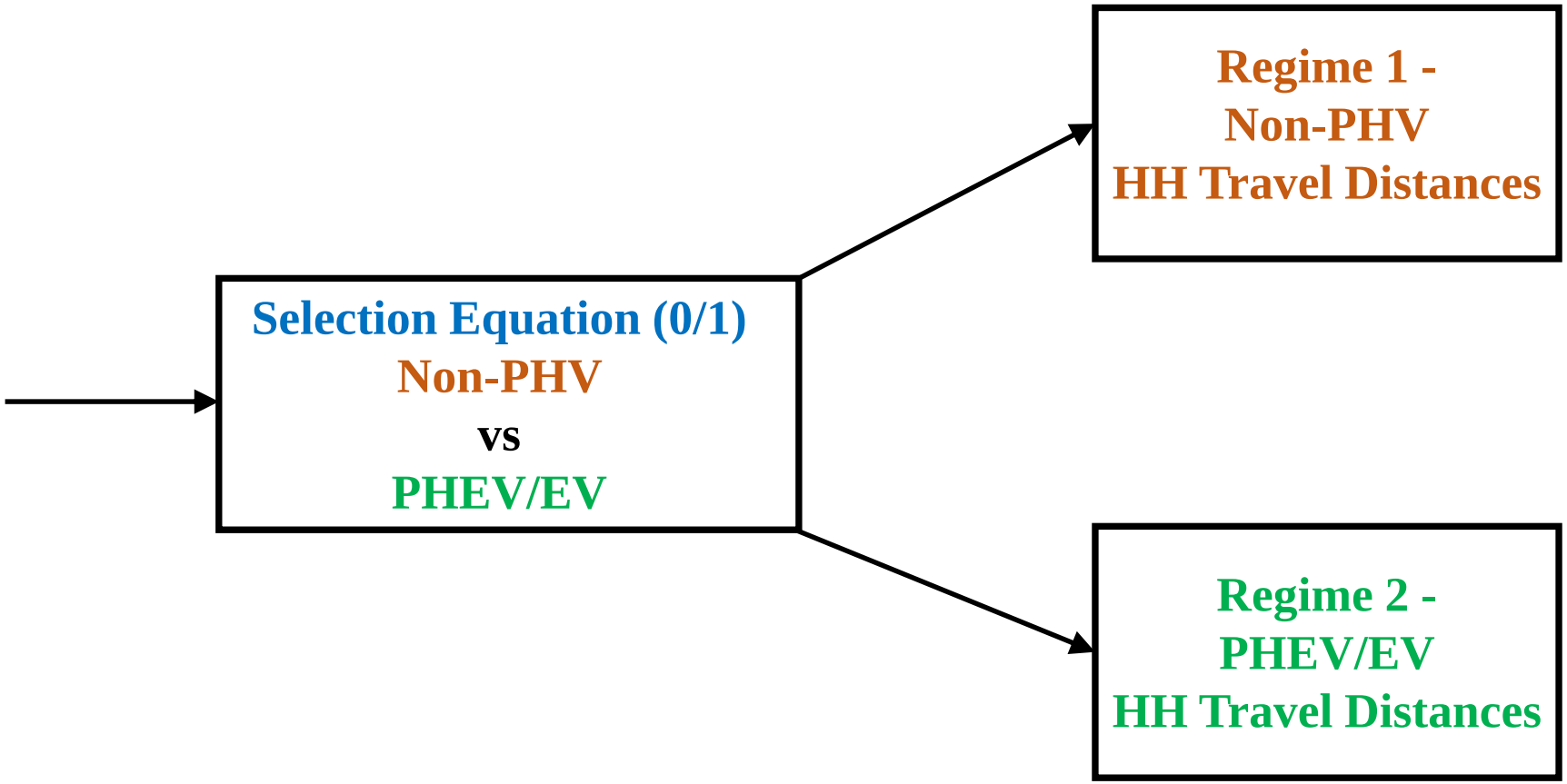
Households that may own "both" non plug-in hybrid and plug-in hybrid not considered.

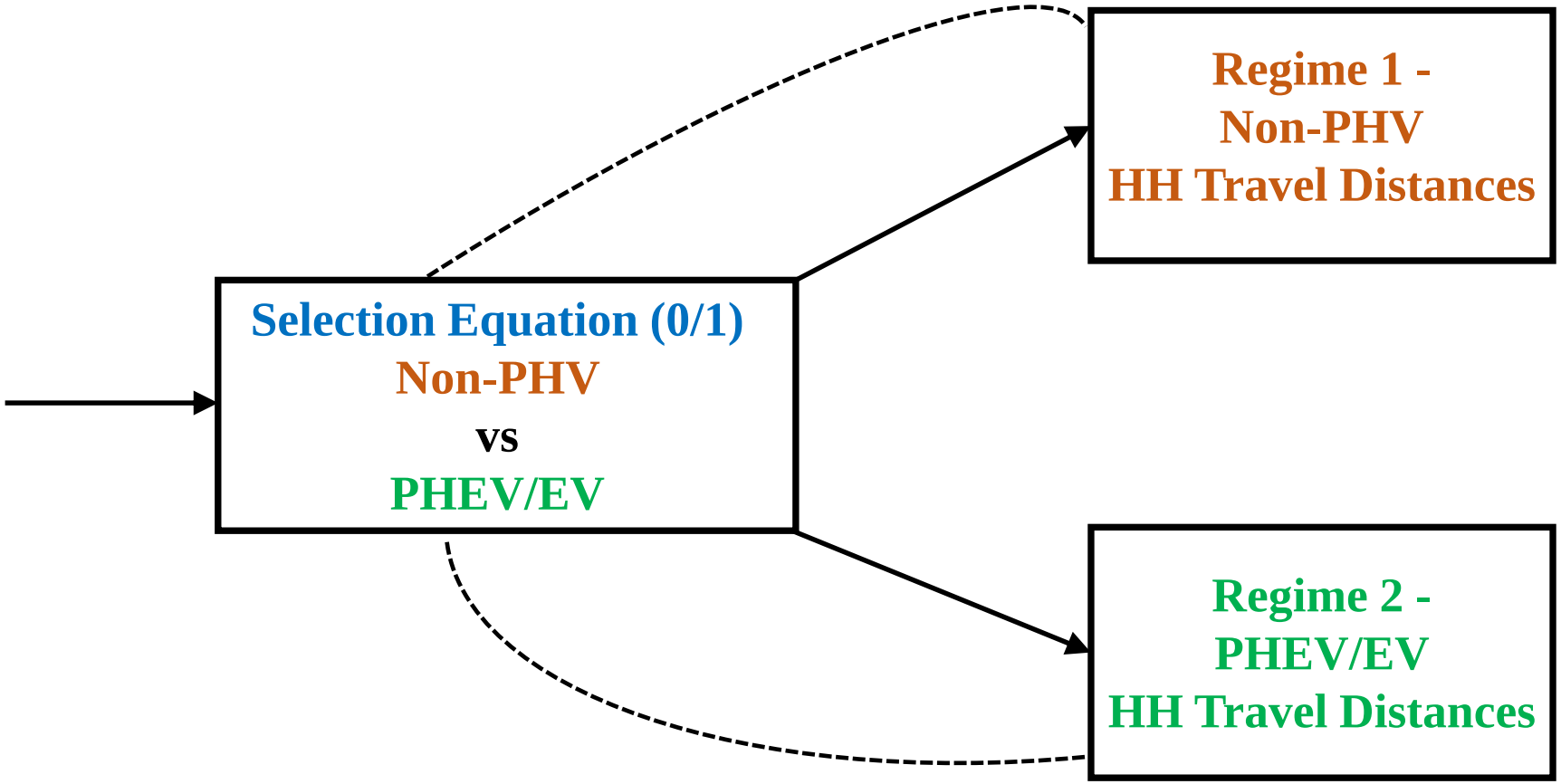
Methodological Approach

- Avoiding *"loss of consistency in a greed to gain efficiency"*
- A Tri-variate Discrete-Continuous Endogenous Regime Switching Framework

Methodological Approach



Methodological Approach



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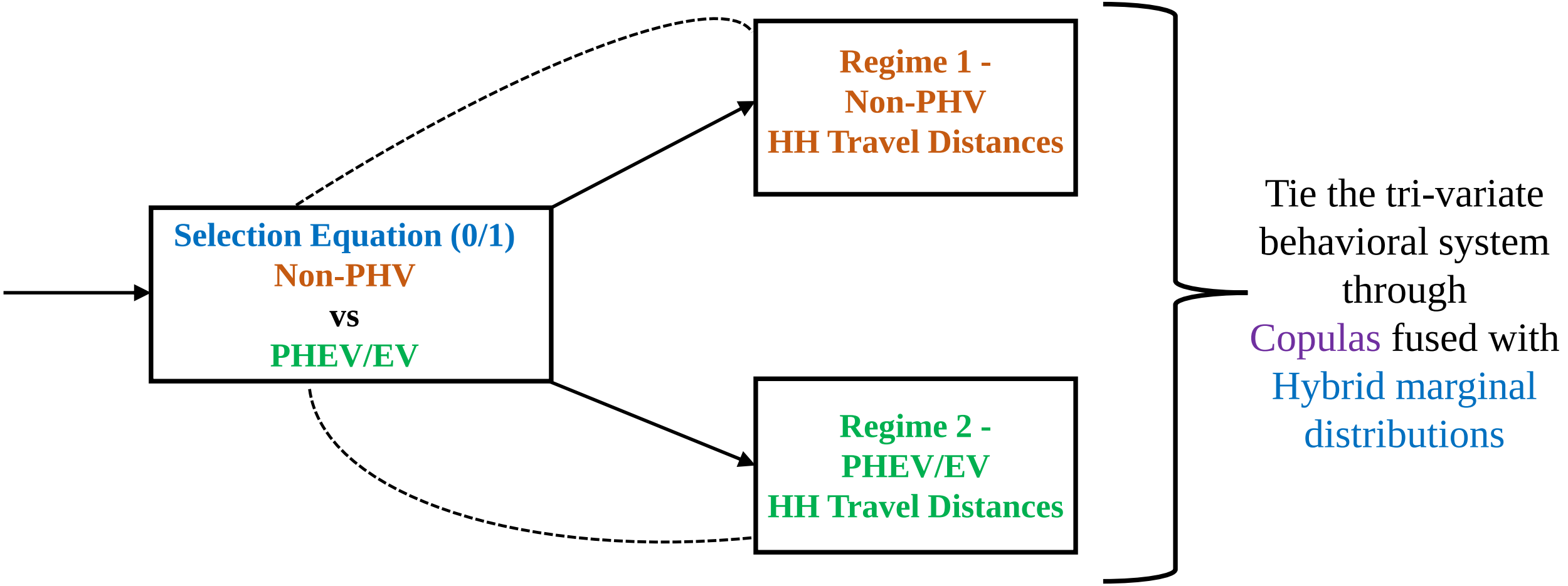

Mathematical Exposition

- Selection Equation:

$$S_i = \begin{cases} 0 \; if \; S_i^* = z_i'\gamma + \varepsilon_{si} \leq 0 \\ 1 \; if S_i^* = z_i'\gamma + \varepsilon_{si} > 0 \end{cases}$$

- Endogenous switching model: Two outcomes

$$y_{1i} = x_{1i}'\beta_1 + \varepsilon_{1i} \qquad \text{if } S_i = 1$$

$$y_{0i} = x_{0i}'\beta_0 + \varepsilon_{0i} \qquad \text{if } S_i = 0$$

- Potential dependencies:
  - $(\varepsilon_{si}, \varepsilon_{1i})$ AND $(\varepsilon_{si}, \varepsilon_{0i})$

Copula Approach

$$\aleph(x, y) = C_\theta(\{A(x), B(y)\}$$

- Stochastic dependence governed by copula:
- Different marginal distributions

Copula Families & Marginal Distributions

Table 1. Copula functions

Copula name	$C(u_1, u_2; \theta)$
Product	$u_1 u_2$
Gaussian	$\Phi_2\{\Phi^{-1}(u_1), \Phi^{-1}(u_2); \theta\}$
FGM	$u_1 u_2\{1 + \theta(1 - u_1)(1 - u_2)\}$
Plackett	$\dfrac{r - \sqrt{r^2 - 4u_1 u_2 \theta(\theta - 1)}}{2(\theta - 1)}$

Archimedean family		$\varphi(t)$
AMH	$u_1 u_2 \{1 - \theta(1 - u_1)(1 - u_2)\}^{-1}$	$\log\left\{\dfrac{1 - \theta(1 - t)}{t}\right\}$
Clayton	$\left(u_1^{-\theta} + u_2^{-\theta} - 1\right)^{-1/\theta}$	$\theta^{-1}\left(t^{-\theta} - 1\right)$
Frank	$-\theta^{-1} \log\left\{1 + \dfrac{(e^{-\theta u_1} - 1)(e^{-\theta u_2} - 1)}{(e^{-\theta} - 1)}\right\}$	$-\log\left(\dfrac{e^{-\theta t} - 1}{e^{-\theta} - 1}\right)$
Gumbel	$\exp\left[-\left\{(-\log u_1)^\theta + (-\log u_2)^\theta\right\}^{1/\theta}\right]$	$\{-\log(t)\}^\theta$
Joe	$1 - \left\{(\widetilde{u}_1)^\theta + (\widetilde{u}_2)^\theta - (\widetilde{u}_1 \widetilde{u}_2)^\theta\right\}^{1/\theta}$	$-\log\left\{1 - (1 - t)^\theta\right\}$

Notes: For Plackett, $r = 1 + (\theta - 1)(u_1 + u_2)$. For Joe, $\widetilde{u}_j = 1 - u_j$.

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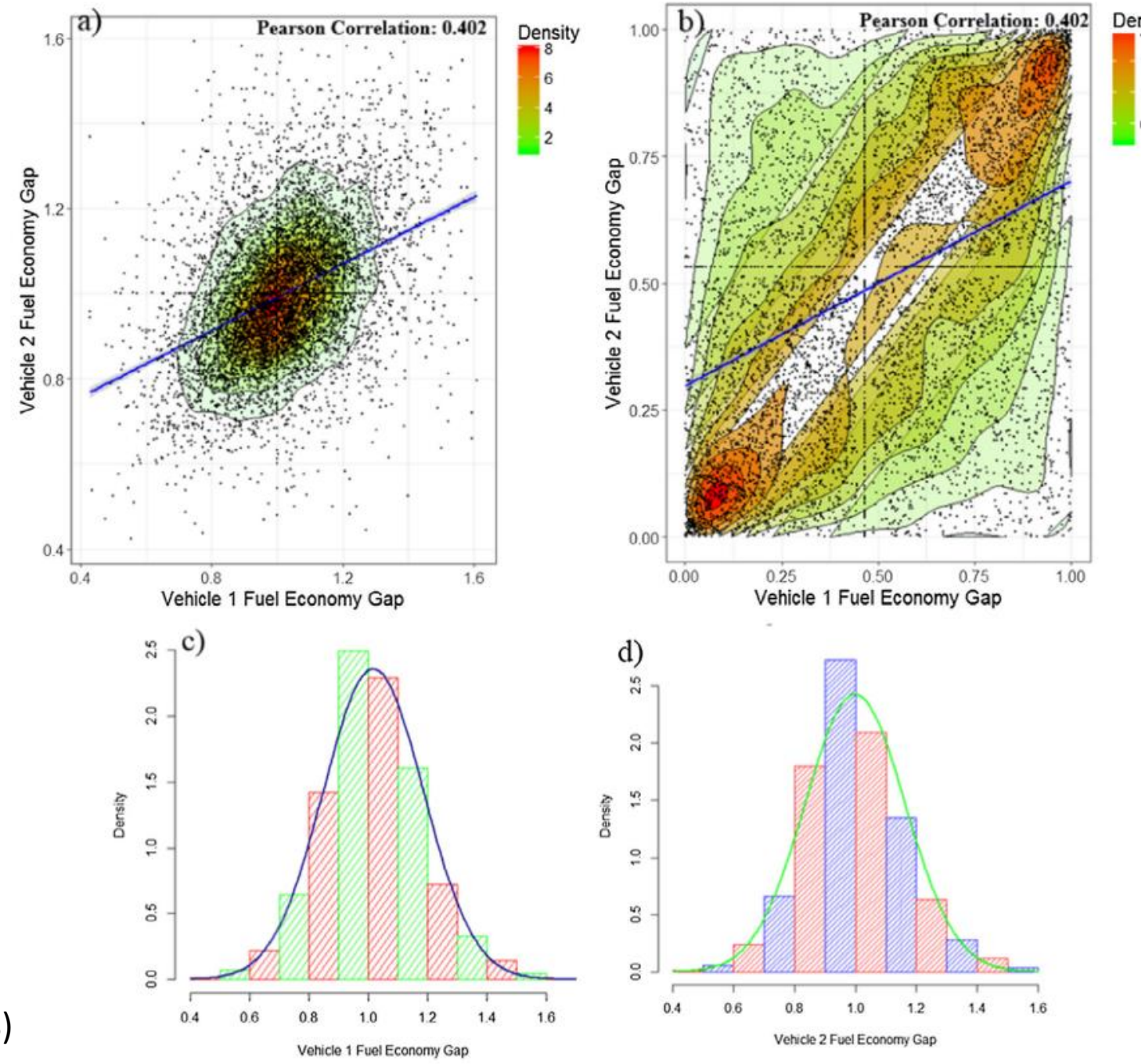
Marginal Distributions

	Probit	Logit	Student's t
Fs	*Y*	*Y*	*NA*
F0	*Y*	*Y*	*Y*
F1	*Y*	*Y*	*Y*

Flexibility:

63 Unique Model Specifications

Illustration

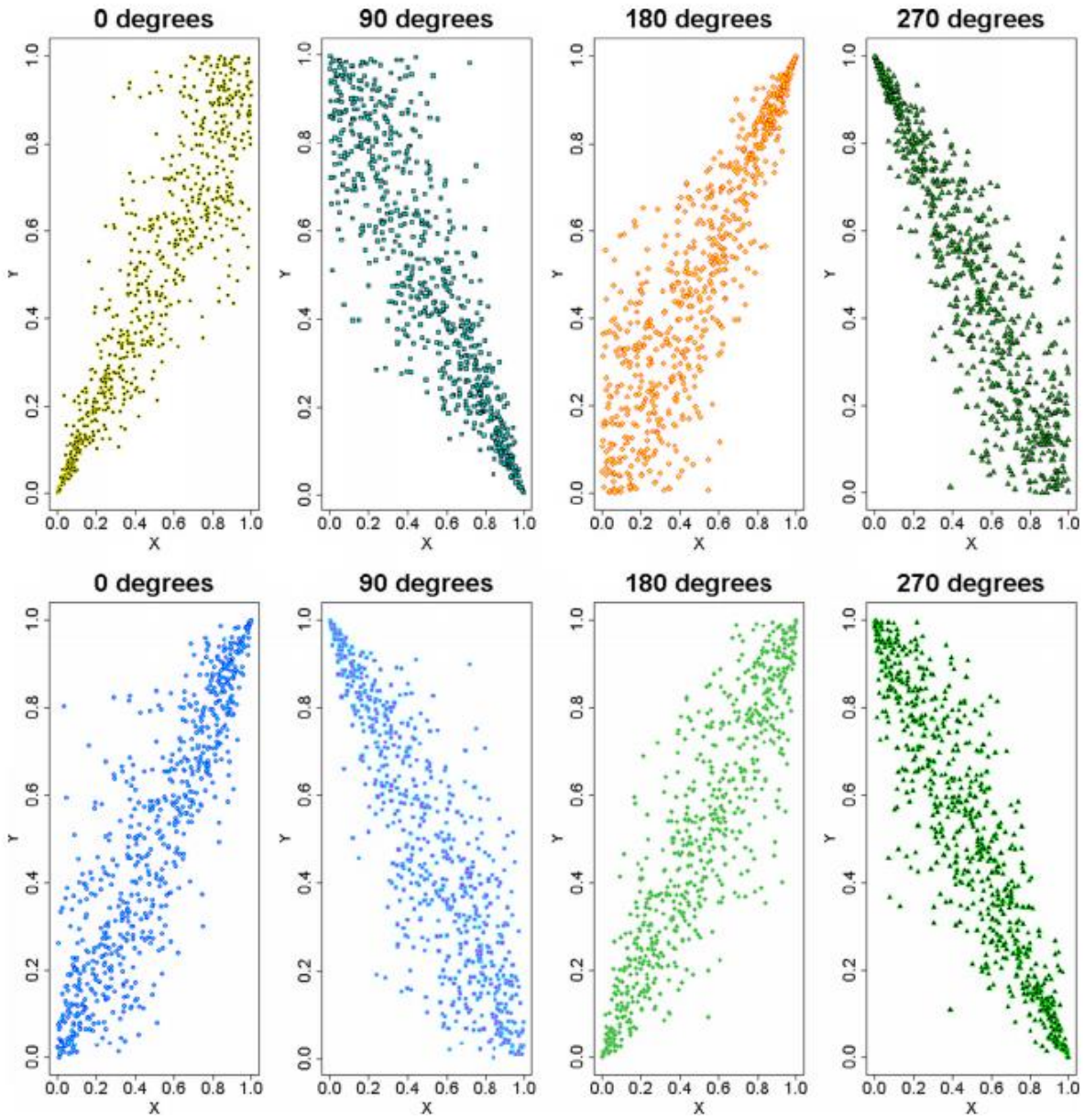


Source: Wali, Greene, Khattak, & Liu (2018)

Illustration

Clayton Copula

Gumbel Copula



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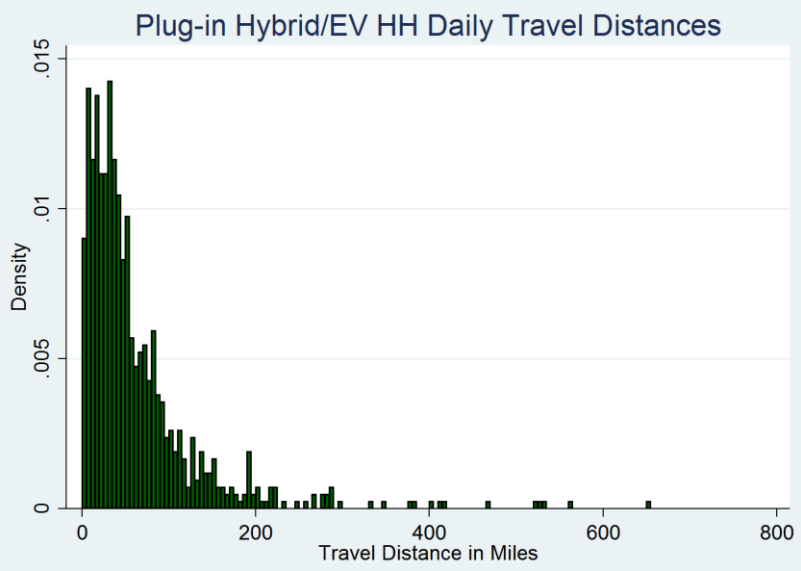
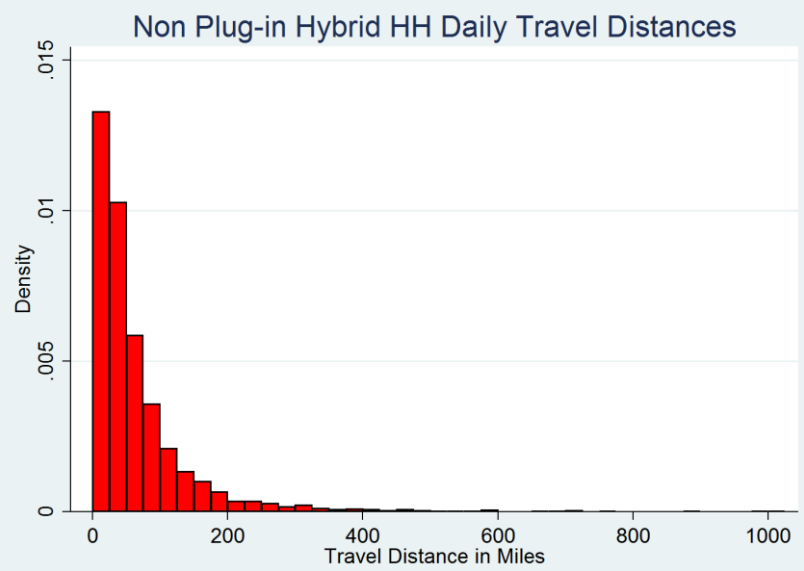
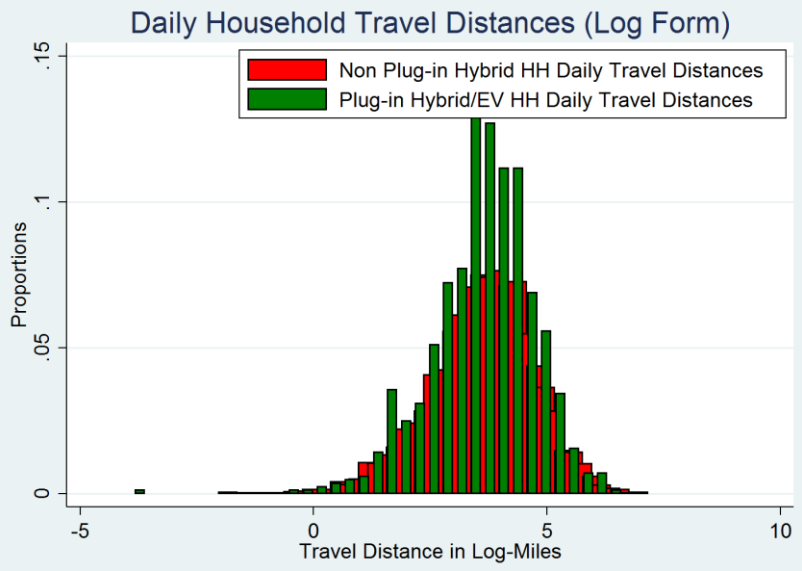
Results – Key Distributions







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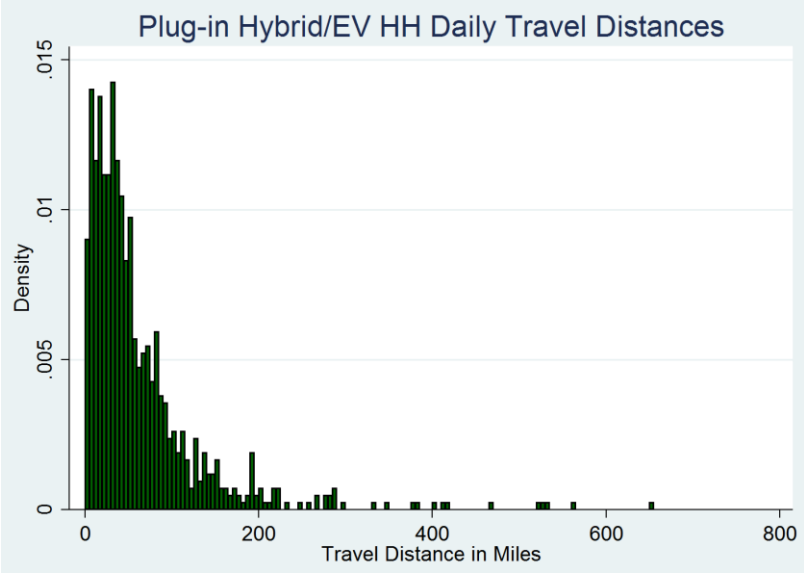

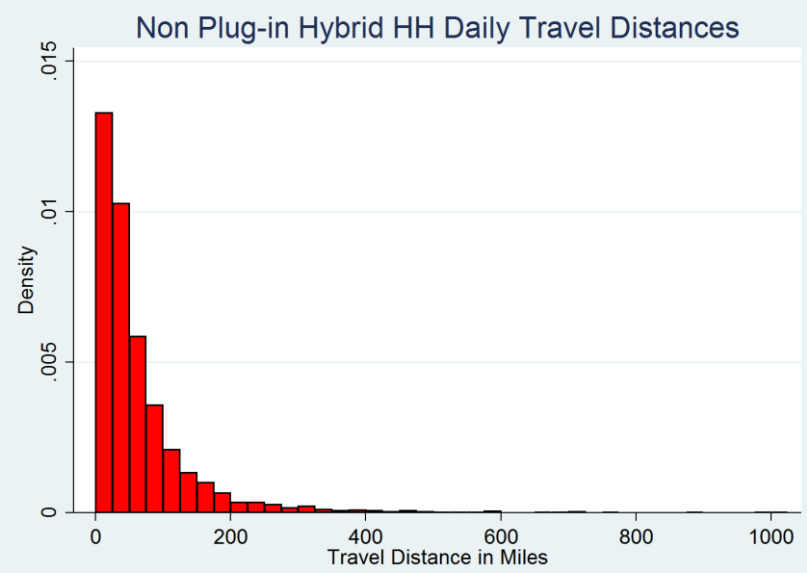

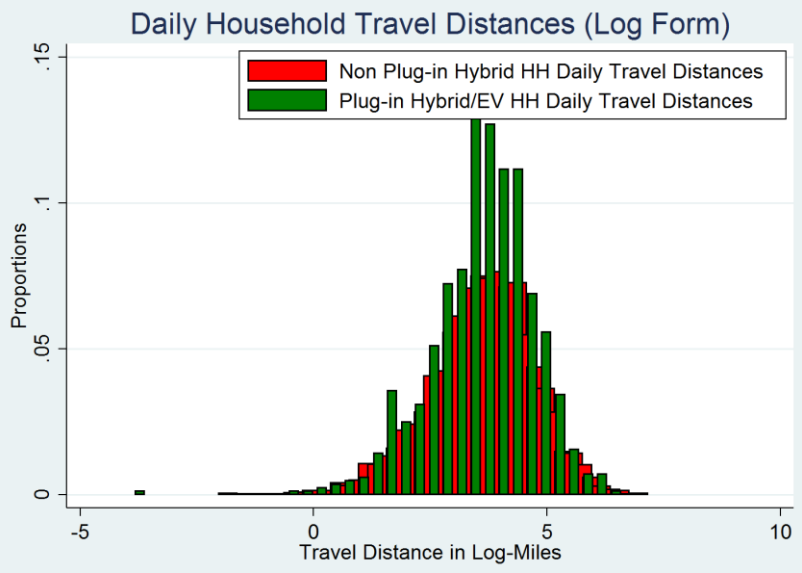

- N = 5231 households
  - N = 839 PHEV/EV households
  - N = 4,389 Non-plug in hybrid households
- 79 households removed that owned both

Descriptive Statistics

Variables	Not Plug-in Hybrid Vehicles (N = 4389)			Plug-in Hybrid/Electric (N = 842)		
	Mean	SD	Min/Max	Mean	SD	Min/Max
Daily HH Distance (Log-form)	**3.61**	1.12	-1.93/6.93	**3.57**	1.10	-3.86/6.47
Household Distance	63.71	78.01	0.14/1024.53	59.27	73.15	0.021/651.68
HH Total Trip Travel Time	**133.65**	106.25	2/1093	**134.18**	101.13	2/739

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Household Income						
Less than $10,000	0.01	0.09	0/1	0.01	0.08	0/1
$10,000 to $14,999	0.01	0.09	0/1	0.00	0.06	0/1
$15,000 to $24,999	0.03	0.16	0/1	0.02	0.12	0/1
$25,000 to $34,999	0.04	0.20	0/1	0.02	0.13	0/1
$35,000 to $49,999	0.07	0.26	0/1	0.04	0.20	0/1
$50,000 to $74,999	0.15	0.36	0/1	0.09	0.29	0/1
$75,000 to $99,999	0.17	0.38	0/1	0.11	0.31	0/1
$100,000 to $124,999	0.15	0.36	0/1	0.16	0.36	0/1
$125,000 to $149,999	0.10	0.30	0/1	0.10	0.30	0/1
$150,000 to $199,999	**0.11**	0.31	0/1	**0.15**	0.36	0/1
$200,000 or more	**0.13**	0.34	0/1	**0.28**	0.45	0/1

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Housing Status						
Own house	**0.87**	0.34	0/1	**0.91**	0.29	0/1
Rent	0.13	0.33	0/1	0.09	0.28	0/1
Number of employed members	**1.27**	0.93	0/6	**1.36**	0.89	0/5
Number of vehicles	**2.35**	1.10	1/10	**2.68**	1.24	1/12
Count of HH trips on travel day	9.52	6.06	1/60	10.19	6.51	2/42

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Household Income						
Less than $10,000	0.01	0.09	0/1	0.01	0.08	0/1
$10,000 to $14,999	0.01	0.09	0/1	0.00	0.06	0/1
$15,000 to $24,999	0.03	0.16	0/1	0.02	0.12	0/1
$25,000 to $34,999	0.04	0.20	0/1	0.02	0.13	0/1
$35,000 to $49,999	0.07	0.26	0/1	0.04	0.20	0/1
$50,000 to $74,999	0.15	0.36	0/1	0.09	0.29	0/1
$75,000 to $99,999	0.17	0.38	0/1	0.11	0.31	0/1
$100,000 to $124,999	0.15	0.36	0/1	0.16	0.36	0/1
$125,000 to $149,999	0.10	0.30	0/1	0.10	0.30	0/1
$150,000 to $199,999	**0.11**	0.31	0/1	**0.15**	0.36	0/1
$200,000 or more	**0.13**	0.34	0/1	**0.28**	0.45	0/1
Housing Status						
Own house	**0.87**	0.34	0/1	**0.91**	0.29	0/1
Rent	0.13	0.33	0/1	0.09	0.28	0/1
Number of employed members	**1.27**	0.93	0/6	**1.36**	0.89	0/5
Number of vehicles	**2.35**	1.10	1/10	**2.68**	1.24	1/12
Count of HH trips on travel day	9.52	6.06	1/60	10.19	6.51	2/42
Life cycle classification of HH						
2+ adults, retired, no children	0.28	0.45	0/1	0.24	0.43	0/1
Daily bike use	0.02	0.13	0/1	0.03	0.17	0/1
Daily bus use	0.01	0.11	0/1	0.01	0.08	0/1
Daily smartphone use to access internet	**0.81**	0.40	0/1	**0.88**	0.33	0/1
Daily internet use	**0.96**	0.18	0/1	**0.99**	0.11	0/1
Travel is NOT a financial burden	**0.09**	0.28	0/1	**0.16**	0.36	0/1

Model Selection (ICOMP)

	Marginal Distributions						
Copula Specification	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Hybrid Copulas							
Product	19810.87	19726.34	19727.63	19570.75	19735.08	19727.36	19733.52
Gaussian	**19820.2**	19734.93	19736.18	19565.34	19743.81	19734.89	19741.29
FGM	19782.04	19733.04	19734.2	19559.4	19741.61	19729.17	19735.43
Plackett	19741.8	19735.41	19736.6	**19551.2**	19736.73	19728.42	19727.42
Archimedian Copulas							
Ali-Mikhael-Haq	19788.04	19733.01	19734.24	19560.87	19741.67	19730.62	19736.82
Clayton	19827.99	19743.47	---	19574.73	---	---	---
Frank	---	---	19736.27	19554.91	19742.05	19726.63	19731.09
Gumbel	19786.98	19736.97	19738.08	19563.35	19735.63	19742.95	19739.46
Joe	19788.28	19716.21	19717.3	19551.72	19722.83	19723.36	19727.82

ICOMP Source: Bozdogan, 2000

Model Selection (ICOMP)

	Marginal Distributions						
Copula Specification	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Hybrid Copulas							
Product	19810.87	19726.34	19727.63	19570.75	19735.08	19727.36	19733.52
Gaussian	**19820.2**	19734.93	19736.18	19565.34	19743.81	19734.89	19741.29
FGM	19782.04	19733.04	19734.2	19559.4	19741.61	19729.17	19735.43
Plackett	19741.8	19735.41	19736.6	**19551.2**	19736.73	19728.42	19727.42
Archimedian Copulas							
Ali-Mikhael-Haq	19788.04	19733.01	19734.24	19560.87	19741.67	19730.62	19736.82
Clayton	19827.99	19743.47	---	19574.73	---	---	---
Frank	---	---	19736.27	19554.91	19742.05	19726.63	19731.09
Gumbel	19786.98	19736.97	19738.08	19563.35	19735.63	19742.95	19739.46
Joe	19788.28	19716.21	19717.3	19551.72	19722.83	19723.36	19727.82

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DIFFERENT MARGINAL DISTRIBUTIONS ARE:
    1. normal/normal/normal
    2. logistic/logistic/logistic
    3. normal/logsitic/logistic
    4. normal/t-dist/t-dist
    5. normal/logistic/t-dist
    6. normal/t-dist/logistic
    7. logistic/t-dist/t-dist
```

ICOMP Source: Bozdogan, 2000

Model Selection (ICOMP)

	Marginal Distributions						
Copula Specification	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Hybrid Copulas							
Product	19810.87	19726.34	19727.63	19570.75	19735.08	19727.36	19733.52
Gaussian	**19820.2**	19734.93	19736.18	19565.34	19743.81	19734.89	19741.29
FGM	19782.04	19733.04	19734.2	19559.4	19741.61	19729.17	19735.43
Plackett	19741.8	19735.41	19736.6	**19551.2**	19736.73	19728.42	19727.42
Archimedian Copulas							
Ali-Mikhael-Haq	19788.04	19733.01	19734.24	19560.87	19741.67	19730.62	19736.82
Clayton	19827.99	19743.47	---	19574.73	---	---	---
Frank	---	---	19736.27	19554.91	19742.05	19726.63	19731.09
Gumbel	19786.98	19736.97	19738.08	19563.35	19735.63	19742.95	19739.46
Joe	19788.28	19716.21	19717.3	19551.72	19722.83	19723.36	19727.82

- Red indicates the ICOMP statistic for traditional Gaussion copula model with normal margins
- Green indicates the best-fit Plackett copula model with Type 4 marginal distributions

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```
DIFFERENT MARGINAL DISTRIBUTIONS ARE:
    1. normal/normal/normal
    2. logistic/logistic/logistic
    3. normal/logsitic/logistic
    4. normal/t-dist/t-dist
    5. normal/logistic/t-dist
    6. normal/t-dist/logistic
    7. logistic/t-dist/t-dist
```

ICOMP Source: Bozdogan, 2000

Model Selection (ICOMP)

- Green indicates the best-fit Plackett-Joe copula model with Type 4 marginal distributions

	Type 4 Margins	
Regime 0: Plackett	AIC	ICOMP
Regime 1: Plackett	19551.22	19728.4
Regime 1: Product	19558.02	19728.64
Regime 1: Gaussian	19552.03	19729.21
Regime 1: FGM	19559.91	19737.09
Regime 1: AMH	19559.91	19737.09
Regime 1: Clayton	19560.02	19737.21
Regime 1: Frank	19560.02	19737.2
Regime 1: Gumbel	19554.76	19731.94
Regime 1: Joe	19547.8	**19724.98**
Regime 1: Plackett		
Regime 1: Plackett	19551.22	19728.4
Regime 0: Product	19564.54	19735.16
Regime 0: Gaussian	19565.02	19742.2
Regime 0: FGM	19550.77	19727.96
Regime 0: AMH	19552.38	19729.57
Regime 0: Clayton	19566.54	19743.72
Regime 0: Frank	19547.87	19725.05
Regime 0: Gumbel	19559.2	19736.38
Regime 0: Joe	19554.54	19731.72

ICOMP Source: Bozdogan, 2000

Estimation Results

Variables	Selection Equation (1/0)	
	β	t-stat
Constant	-1.84	-12.96
Household Income		
Less than $10,000	---	---
$15,000 to $24,999	---	---
$25,000 to $34,999	---	---
High income (1 if income > 100,000)	0.41	9.40
Housing Status		
Own house	0.14	2.28
Rent	---	---
Life cycle classification of HH		
2+ adults, retired, no children	---	---
Number of employed members	---	---
Count of HH trips on travel day	---	---
Three or more vehicles	---	---
Daily bike use	0.28	2.01
Daily smartphone use to access internet	0.18	3.16
Daily internet use	0.33	2.31
Travel is NOT a financial burden	0.20	3.38
Identification/Copula Parameters		
Copula device	---	
Marginal distribution	Normal/Probit	
Sigma (Regimes Specific)	---	---
Dependence (Regime Specific)	---	---
Kendall Tau	---	---
DOF - t marginal distributions	---	---

Estimation Results

Variables	Selection Equation (1/0)		Regime 0 (Not Plug-in Hybrid)	
	β	t-stat	β	t-stat
Constant	-1.84	-12.96	3.04	77.69
Household Income				
Less than $10,000	---	---	-0.41	-2.37
$15,000 to $24,999	---	---	-0.44	-4.51
$25,000 to $34,999	---	---	-0.26	-3.26
High income (1 if income > 100,000)	0.41	9.40	---	---
Housing Status				
Own house	0.14	2.28	---	---
Rent	---	---	-0.22	-4.47
Life cycle classification of HH				
2+ adults, retired, no children	---	---	-0.14	-3.97
Number of employed members	---	---		
Count of HH trips on travel day	---	---	0.06	23.50
Three or more vehicles	---	---		
Daily bike use	0.28	2.01	-0.59	-4.79
Daily smartphone use to access internet	0.18	3.16	---	---
Daily internet use	0.33	2.31	---	---
Travel is NOT a financial burden	0.20	3.38	---	---
Identification/Copula Parameters				
Copula device	---		Plackett copula	
Marginal distribution	Normal/Probit		t-distribution	
Sigma (Regimes Specific)	---	---	0.98	43.60
Dependence (Regime Specific)	---	---	0.30	4.14
Kendall Tau	---	---	-0.26	
DOF - t marginal distributions	---	---	14.93	

Estimation Results

Variables	Selection Equation (1/0)		Regime 0 (Not Plug-in Hybrid)	
	β	t-stat	β	t-stat
Constant	-1.84	-12.96	3.04	77.69
Household Income				
Less than $10,000	---	---	-0.41	-2.37
$15,000 to $24,999	---	---	-0.44	-4.51
$25,000 to $34,999	---	---	-0.26	-3.26
High income (1 if income > 100,000)	0.41	9.40	---	---
Housing Status				
Own house	0.14	2.28	---	---
Rent	---	---	-0.22	-4.47
Life cycle classification of HH				
2+ adults, retired, no children	---	---	-0.14	-3.97
Number of employed members	---	---		
Count of HH trips on travel day	---	---	0.06	23.50
Three or more vehicles	---	---		
Daily bike use	0.28	2.01	-0.59	-4.79
Daily smartphone use to access internet	0.18	3.16	---	---
Daily internet use	0.33	2.31	---	---
Travel is NOT a financial burden	0.20	3.38	---	---
Identification/Copula Parameters				
Copula device	---		**Plackett copula**	
Marginal distribution	Normal/Probit		**t-distribution**	
Sigma (Regimes Specific)	---	---	0.98	43.60
Dependence (Regime Specific)	---	---	**0.30**	4.14
Kendall Tau	---	---	**-0.26**	
DOF - t marginal distributions	---	---	14.93	

Estimation Results

Variables	Selection Equation (1/0)		Regime 0 (Not Plug-in Hybrid)		Regime 1 (Plug-in Hybrid/Electric)	
	β	t-stat	β	t-stat	β	t-stat
Constant	-1.84	-12.96	3.04	77.69	1.75	11.45
Household Income						
Less than $10,000	---	---	-0.41	-2.37	---	---
$15,000 to $24,999	---	---	-0.44	-4.51	---	---
$25,000 to $34,999	---	---	-0.26	-3.26		
High income (1 if income > 100,000)	0.41	9.40	---	---	0.53	5.96
Housing Status						
Own house	0.14	2.28	---	---	---	---
Rent	---	---	-0.22	-4.47	---	---
Life cycle classification of HH						
2+ adults, retired, no children	---	---	-0.14	-3.97	---	---
Number of employed members	---	---			0.14	3.30
Count of HH trips on travel day	---	---	0.06	23.50	0.04	6.86
Three or more vehicles	---	---			0.32	3.50
Daily bike use	0.28	2.01	-0.59	-4.79	-0.29	-1.83
Daily smartphone use to access internet	0.18	3.16	---	---	---	---
Daily internet use	0.33	2.31	---	---	---	---
Travel is NOT a financial burden	0.20	3.38	---	---	---	---
Identification/Copula Parameters						
Copula device	---		**Plackett copula**		Joe copula	
Marginal distribution	Normal/Probit		**t-distribution**		t-distribution	
Sigma (Regimes Specific)	---	---	0.98	43.60	0.89	15.05
Dependence (Regime Specific)	---	---	**0.30**	4.14	1.81	14.57
Kendall Tau	---	---	**-0.26**		0.31	
DOF - t marginal distributions	---	---	14.93		10.38	

Estimation Results

Variables	Selection Equation (1/0)		Regime 0 (Not Plug-in Hybrid)		Regime 1 (Plug-in Hybrid/Electric)	
	β	t-stat	β	t-stat	β	t-stat
Constant	-1.84	-12.96	3.04	77.69	1.75	11.45
Household Income						
Less than $10,000	---	---	-0.41	-2.37	---	---
$15,000 to $24,999	---	---	-0.44	-4.51	---	---
$25,000 to $34,999	---	---	-0.26	-3.26		
High income (1 if income > 100,000)	0.41	9.40	---	---	0.53	5.96
Housing Status						
Own house	0.14	2.28	---	---	---	---
Rent	---	---	-0.22	-4.47	---	---
Life cycle classification of HH						
2+ adults, retired, no children	---	---	-0.14	-3.97	---	---
Number of employed members	---	---			0.14	3.30
Count of HH trips on travel day	---	---	0.06	23.50	0.04	6.86
Three or more vehicles	---	---			0.32	3.50
Daily bike use	0.28	2.01	-0.59	-4.79	-0.29	-1.83
Daily smartphone use to access internet	0.18	3.16	---	---	---	---
Daily internet use	0.33	2.31	---	---	---	---
Travel is NOT a financial burden	0.20	3.38	---	---	---	---
Identification/Copula Parameters						
Copula device	---		**Plackett copula**		**Joe copula**	
Marginal distribution	Normal/Probit		**t-distribution**		**t-distribution**	
Sigma (Regimes Specific)	---	---	0.98	43.60	0.89	15.05
Dependence (Regime Specific)	---	---	**0.30**	4.14	**1.81**	14.57
Kendall Tau	---	---	**-0.26**		**0.31**	
DOF - t marginal distributions	---	---	14.93		10.38	

Estimation Results

Variables	Selection Equation (1/0)		Regime 0 (Not Plug-in Hybrid)		Regime 1 (Plug-in Hybrid/Electric)	
	β	t-stat	β	t-stat	β	t-stat
Constant	-1.84	-12.96	3.04	77.69	1.75	11.45
Household Income						
Less than $10,000	---	---	-0.41	-2.37	---	---
$15,000 to $24,999	---	---	-0.44	-4.51	---	---
$25,000 to $34,999	---	---	-0.26	-3.26		
High income (1 if income > 100,000)	0.41	9.40	---	---	0.53	5.96
Housing Status						
Own house	0.14	2.28	---	---	---	---
Rent	---	---	-0.22	-4.47	---	---
Life cycle classification of HH						
2+ adults, retired, no children	---	---	-0.14	-3.97	---	---
Number of employed members	---	---			0.14	3.30
Count of HH trips on travel day	---	---	0.06	23.50	0.04	6.86
Three or more vehicles	---	---			0.32	3.50
Daily bike use	0.28	2.01	-0.59	-4.79	-0.29	-1.83
Daily smartphone use to access internet	0.18	3.16	---	---	---	---
Daily internet use	0.33	2.31	---	---	---	---
Travel is NOT a financial burden	0.20	3.38	---	---	---	---
Identification/Copula Parameters						
Copula device	---		Plackett copula		Joe copula	
Marginal distribution	Normal/Probit		t-distribution		t-distribution	
Sigma (Regimes Specific)	---	---	0.98	43.60	0.89	15.05
Dependence (Regime Specific)	---	---	0.30	4.14	1.81	14.57
Kendall Tau	---	---	-0.26		0.31	
DOF - t marginal distributions	---	---	**14.93**		**10.38**	

Treatment Effects

Treatment Effects	Trivariate-Joint Normality	Trivariate-Joint Switching	Trivariate-Joint Switching
	Gaussian copulas	Plackett-Joe Copulas	Plackett-Joe Copulas
	Normal margins	Normal margins	Normal/t-distribution/t-distribution
Average Treatment Effect (ATE) in log-miles	-0.384	-1.38	**-0.929**

Closure

- …. Plug-in Hybrid/EV households travel **on-average significantly less** distance than their counterparts.
- Presence of self-selection effects.
- Standard approaches (if assumptions violated): provide misleading effects.
- Joint estimation of the behavioral system: Better than standard approaches.
- Given joint estimation, not only different marginal distributions, but also dependence structures yield much different effects.
- Future Work:
  - Analyze households that have both HEVs and PHEVs (Extend methodological framework)
  - Link HEV- and PHEV-VMT to each of the vehicle type
  - Look into vehicle use of conventional vehicles vis-à-vis AFVs

Thank YOU

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OAK RIDGE National Laboratory