16th International Conference on Travel Behaviour Research IATBR
Santiago, Chile – December 11-15, 2022

Joint models of car segment and fuel type choice for alternative fuel vehicles: application to the English market

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12.12.22

Context

- Since 2009, many governments have been encouraging the uptake of low emission vehicles, with measures to reduce the cost gap between **alternative fuel vehicles (AFV)** and **internal combustion engine (ICE)** vehicles, including:
  - Purchase subsidies.
  - Tax exemptions.
  - The development of charging infrastructure.
- In the UK, the current "**Road to Zero**" strategy sets the "*ambition*" that almost every car and van will be zero emission in 2050, ending the sale of new Petrol and Diesel cars by 2030, and of hybrid vehicles by 2035 (Hirst, 2020).

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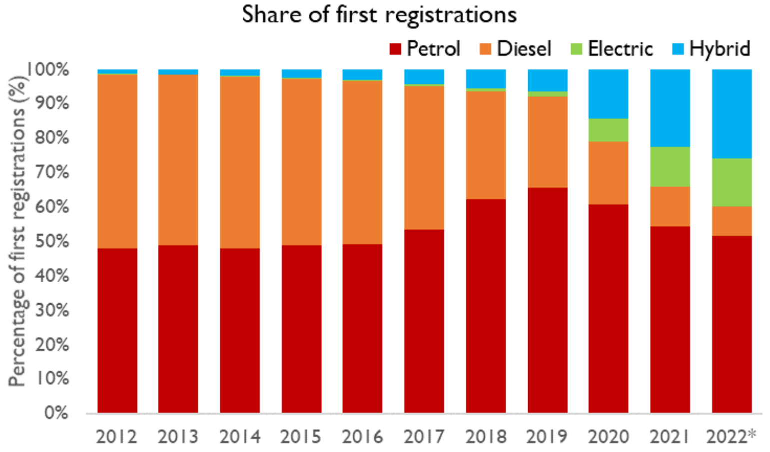
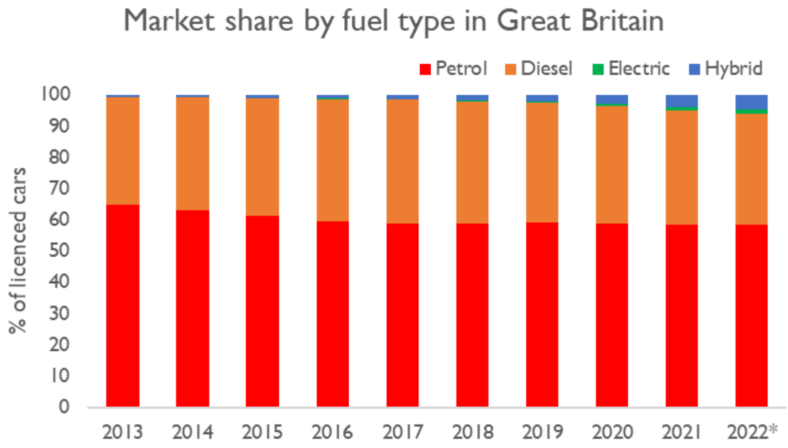
Context

- How is adoption going?



Source: UK Department for Transport (2022)
Table 'Veh0153 - Vehicles registered for the first time by body type and fuel type'



Source: UK Department for Transport (2022)
Table 'Veh1103 - Licensed vehicles at the end of the quarter by body type and fuel type'

- Similar trends across several countries (e.g., UE, China).
- Understanding and modelling the **demand for AFVs** is a necessity.

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Outline

- Aim and contribution
- Data
- Modelling framework
- Results
- Conclusions
- Limitations and future research

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Aim and contribution

- Most articles in the literature deal with *either* fuel type OR vehicle type choice.
- However, it might be relevant to consider both, because **different vehicles could fulfil different purposes**.

Segment	Example models	NTS market share by segment (%)	
		ICE (Petrol/Diesel)	AFV (Electric/Hybrid)
A: Mini	Fiat 500, Hyundai i10	11.6	0.9
B: Small	Renault Clyo, Vauxhall Corsa	25.5	19.8
C: Medium	Ford Focus, Volkswagen Golf	20.4	27.4
D: Large	Peugeot 406, Mazda 6	10.9	8.5
E: Executive	Mercedes Benz E220, Jaguar XF	2.7	3.8
F: Luxury	Porsche Panamera, BMW 7-Series	1.1	4.7
J: SUV	Hyundai Tucson, Toyota RAV-4	18.6	26.4
M: MPV	Citroën C4 Picasso, Ford Galaxy	6.2	8.5
S: Sport	Audi TT, Porsche 911	3.0	0.0

Source: Adapted from the National Travel Survey (2020)

An ICE car is 1.8 times more likely to belong to the mini or small segments than AFVs.

An AFV is 1.4 times more likely to belong to the J or M segments than an ICE

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Aims and contribution

- Few studies focusing on joint segment and fuel type choice:
  - Brownstone *et al.* (1996): RP data, separate models for 1- and 2-car households, utilises detailed history of car ownership.
  - Higgins *et al.* (2007): SP data, separate models per segment.
  - Hess *et al.* (2012): SP data, cross-nested logit of segment and fuel type.
  - Mabit (2014): RP data of car sales, highly detailed information for car alternatives. *Dummies* for car segments.
  - Fernandez-Antolin *et al.* (2018): RP data of car sales, highly detailed for chosen alternatives, no information on unchosen alternatives.

Aims and contribution

- In the present study…
  - We estimate a joint choice **model of vehicle segment and fuel type** for households in England…
  - …considering a **correlation structure** that accounts for substitution at both levels…
  - …with a full **revealed preference (RP)** approach…
  - …using **real data** at disaggregate **(household) level** and…
  - …a **detailed dataset of attributes of vehicles in the market**…
  - …using a **holdout dataset for validation**.

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Data

- We merge two sources of information:

1. The **National Travel Survey (NTS)**
    - An annual data collection of transport information for households in England.
    - Detailed socioeconomic attributes, some location attributes, car characterisation up to the make/model level.
    - Data from **34,081 households** (with at least 1 personal car) from the 2013–2020 NTS sample, totalling **47,375 cars.**

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Data

- We merge two sources of information:

2. The **Teoalida dataset**:
    - A privately sourced dataset that synthesises catalogue records (*Auto Motor und Sport*, *Parker's Car Price Guide*) from UK vehicle sellers (Teoalida) between 1970 and 2021.
    - The highly detailed dataset contains **105** makes, **1,107** models and **90,046** model variations (trims) and attributes.

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Outline

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Modelling framework

- We model **vehicle purchases**.
- We do not consider *all* the available alternatives (trims, makes, models) for every purchase:
    - There are about 4,200 alternatives available on any given year.
    - The household is unlikely to consider *all* these alternatives in its decision.
    - Uncovering the heuristics involved in choosing a specific make, model, and trim requires additional information (and it is out of the scope of this project).

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Modelling framework

- Our alternatives are **combinations** of 4 fuel types (petrol, Diesel, electric, and hybrid-electric), and the 9 previously defined vehicle segments.

Segment	Example models	NTS Market Share (%)
A: Mini	Fiat 500, Hyundai i10	11.2
B: Small	Renault Clyo, Vauxhall Corsa	25.3
C: Medium	Ford Focus, Volkswagen Golf	20.7
D: Large	Peugeot 406, Mazda 6	10.8
E: Executive	Mercedes Benz E220, Jaguar XF	2.7
F: Luxury	Porsche Panamera, BMW 7-Series	1.3
J: SUV	Hyundai Tucson, Toyota RAV-4	18.9
M: MPV	Citroën C4 Picasso, Ford Galaxy	6.3
S: Sport	Audi TT, Porsche 911	2.8

Source: Adapted from the National Travel Survey (2020)

- Between 21 and 79 alternatives for each purchase year.

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Modelling framework

- A **cross-nested logit model:**
  - 2 **fuel type** nests (AFV and ICE).
  - 9 **car segment** nests (A, B, C, D, E, F, J, M, S).
  - Each elementary alternative (combination of fuel type and segment) belongs simultaneously to *exactly* one fuel type nest and one car segment nest.
  - An **allocation parameter** measures the degree of association with each nest.

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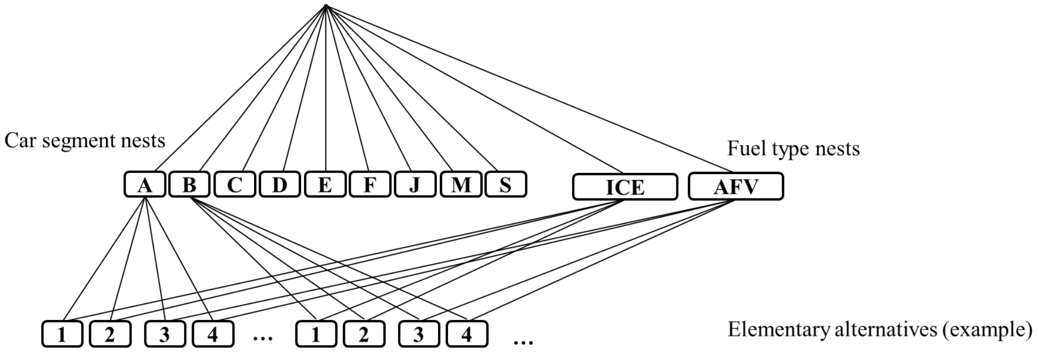
Modelling framework

- A **cross-nested logit model:**

$$P(i) = \sum_{m=1}^{M} \frac{\left(\sum_{j \in S_m} \left(\alpha_{jm} \exp(\hat{V}_j)\right)^{1/\phi_m}\right)^{\phi_m}}{\sum_{l=1}^{M} \left(\sum_{i \in S_m} \left(\alpha_{jl} \exp(\hat{V}_j)\right)^{1/\phi_l}\right)^{\phi_l}} \cdot \frac{\left(\alpha_{im} \exp(\hat{V}_i)\right)^{1/\phi_m}}{\sum_{j=1}^{J} \left(\alpha_{jm} \exp(\hat{V}_j)\right)^{1/\phi_m}}$$



Symbol	Definition	Restrictions
$\hat{V}_i$	Utility of alternative i	–
ϕ_m	Nest parameters for nest m	$0 < \phi_m \leq 1 \ \forall m$
α_{im}	Allocation parameters for alternative j in nest m	$0 \leq \alpha_{jm} \leq 1 \ \forall j, m$ and $\sum_{m=1}^{M} \alpha_{jm} = 1 \ \forall j$ In practice, we estimate: $\alpha_{j,m_1} = \frac{\exp(\alpha_{0j,m_1})}{\exp(\alpha_{0j,m_1}) + \exp(\alpha_{0j,m_2})}$ And we restrict $\alpha_{0j,m_2} = 0 \ \forall j$ In addition, in our best specification all α_{j,m_1} are equal.

Modelling framework

- **Attributes of the utility function:**

Variable type	Name	Alternatives	Unit
Vehicle	Purchase cost	All	£ (thousands)
	Expected annual expense	Petrol and Diesel	£ (thousands)
	Expected annual expense	Electric and Hybrid-Electric	£ (thousands)
	Engine size	Petrol, Diesel, and Hybrid-Electric	l
	Vehicle length	All	m
	Battery size	Electric	kWh
	Charging points network	Electric and Hybrid-Electric	# of points
	Rapid charging points network	Electric and Hybrid-Electric	# of points
	New vehicle dummy	Electric and Hybrid-Electric	Dummy
Other	Density in the household area	Segments J and M only	persons per hectare
Interactions	Vehicle length × Household size	All	metres x persons
	Purchase cost × Low income	All	£ (thousands)
	Purchase cost × Medium income	All	£ (thousands)
	Engine size × Urban household	Petrol, Diesel, and Hybrid-Electric	m^3

Different for new and second hand vehicles

Depends on fuel and energy costs (sourced from Department for Business Energy and Industrial Strategy, 2021).

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Results – 1) Attributes

Alternative	Name	CNL	
		Est.	t-test (0)
Main attributes			
All	Purchase price	-0.019	-14.93
Non-electric	Expected annual expense	-0.328	-16.73
Elec	Expected annual expense	-0.227	-6.99
J, M segments	Urban density	-0.142	-2.72
Electric	Normal charging points	0.084	17.66
Electric	Rapid charging points	0.263	3.62
Electric	Battery size	0.001	0.36
Electric, Hybrid	New car dummy	1.110	11.92
Interactions			
All	Purchase price × Medium income	-0.004	-5.89
All	Purchase price × Lower income	-0.005	-6.44
All	Engine size × Urban household	0.024	5.61
All	Vehicle length × Household size	0.015	3.03
Goodness-of-fit indicators			
-	Log-likelihood*	-117,249	
-	ρ (0)	0.209	
-	ρ (k)	0.070	

- Estimated parameters have the expected signs.
- Lower income groups show higher sensitivity to **purchase price**, hinting to an income effect.
- Higher sensitivities for **annual expense** for non-electric vehicles.

Results – 1) Attributes

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Goodness-of-fit indicators			
-	Log-likelihood*	-117,249	
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- Preferences for **vehicle length** depend on household size (bigger households prefer longer cars).
- Living in a high-density area decreases the probability of buying an **SUV or MPV**.
- The probability of buying an AFV increases if the vehicle is **new**.
- A higher number of **charging points** is correlated with higher probability of buying AFVs.

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Results – 2) Structural parameters

Parameter type	Level	CNL	
		Est.	t-test (1)
Car segment	A (Mini cars)	0.050	-328.75
	B (Small cars)	0.044	-302.05
	C (Medium cars)	0.152	-75.31
	D (Large cars)	0.130	-89.78
	E (Executive cars)	0.163	-43.75
	F (Luxury cars)	1.000	Fixed
	J (Sport utility vehicles)	1.000	Fixed
	M (Multi-purpose vehicles)	0.230	-49.19
	S (Sport cars)	0.561	-9.21
Fuel type	ICE (Petr, Dies)	0.132	-49.48
	AFV (Elec, Hybr)	1.000	Fixed
Allocation	Parameter	-1.985	-35.02

- **Nest parameters** for car segments are all different from 1 except for luxury cars (F) and Sport utility vehicles (J) (possibly due to higher attribute variability in these more expensive segments).
- Highly significant correlation between ICE alternatives, no correlation between AFVs in the same segment.
- The allocation parameter shows that each alternative is more associated with car segment (86%) than with fuel type (14%).

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Results – 3) Elasticities and substitutional patterns

- Direct **purchase price elasticities** range from -0.19 to -1.24.
  - **Higher elasticities**: smaller Diesel cars (A and B segments) and luxury hybrid-electric cars (F and S segments).
  - **Lower elasticities**: J (SUV) and M (MPV) segments.
- **Annual operation cost elasticities** are, on average, lower than purchase price elasticities. The demand for AFV appears less sensitive to operation costs than the demand for ICE vehicles.

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Results – 3) Elasticities and substitutional patterns

- **Cross-elasticities of purchase price** appear to be non-significant.
- Most relevant **cross-elasticities of operation cost**:
  - Petrol and Diesel cars from the same segment (highest value for A segment, 5.81).
  - Petrol and hybrid-electric cars from segments A (0.20) and S (0.21).

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Conclusions

- The full RP-dataset allows analysing household perceptions of vehicle attributes and interactions between segment and fuel type.
- **Fuel type choice is not independent from car segment choice.** A stronger correlation exists between cars from the same segment (in comparison with cars from the same fuel type).
- Awareness for cleaner fuel transport alternatives should be raised considering these differences, **avoiding "one-size-fits-all" campaigns.**

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Conclusions

- Cost parity could be reached in terms of **both purchase price and operation cost**. The second could have a significant effect in demand shifts.
- More attention should be set on the **second-hand market for AFVs**. Purchase price barriers are reduced in the second-hand market.

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