Market Structure Mapping with Interpretable Visual Characteristics

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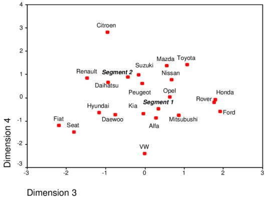
Presenting at:
Marketing Dynamics
May 2025

What is a Market Structure Map?

A common element of market structure analysis is the derivation of a **market structure map**, *that is, a spatial representation of firms' competitive positions relative to one another based on some measure of their competitive relationships (DeSarbo et al. 1993)*

- Graphical representations of product positioning (e.g. Multidimensional Scaling)



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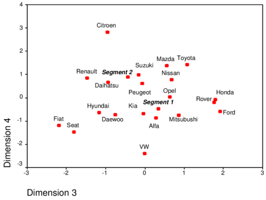

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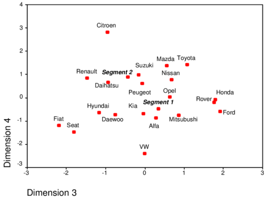

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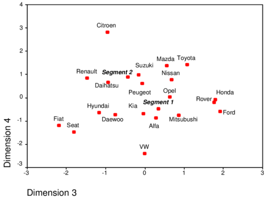

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- Strategic tool for understanding competitive landscape that enable us to:
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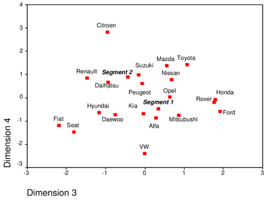
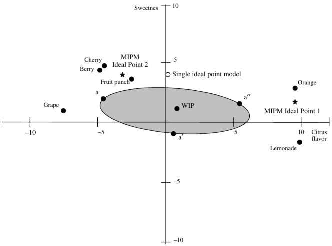
  - Spot new opportunities
  - Identify competitors and evaluate positioning

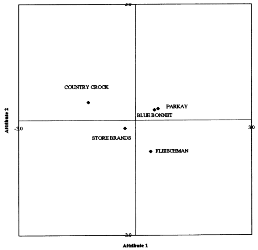


Market Structure Map: Examples

Compositional (Left) & Decompositional (Right)



Lee, Sudhir and Steckel (2002), *Journal of Marketing Research*



Erdem (1996), *Marketing Science*

Compositional (Building up)

- Product characteristics – functional, psychological

Decompositional (Breaking down)

- Survey data by asking 1st and 2nd choices

Market Structure Mapping

Sources of Data

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What's common?

Neither of these approaches have considered visual characteristics.

Are these cars close substitutes?

First, consider *functional* product characteristics:

(A)	**(B)**
\$179,000-\$243,000, 553 HP, 16-23 MPG	From \$242,700, 542-650 HP, 14-22 MPG

Are these cars close substitutes?

First, consider *functional* product characteristics:

(A)	**(B)**
$179,000-$243,000, 553 HP, 16-23 MPG	From $242,700, 542-650 HP, 14-22 MPG
Ferrari California	**Bentley Continental GT**

Importance of Visual Design

Functional characteristics alone are *not sufficient* to even place the car in an appropriate segment (submarket)

Visual design matters

"Exterior look/design is the top reason shoppers avoid a particular vehicle (30%), followed by cost (17%)."

—JD Power Avoider Study 2015

The Challenge

How to quantify visual design?

Quantifying Visual Design

Sisodia, Burnap and Kumar – JMR (2025)

Research Goals

Obtain **human-interpretable** visual characteristics (not outliers) directly from unstructured product image data:

- *automatically discover* and extract characteristics for products

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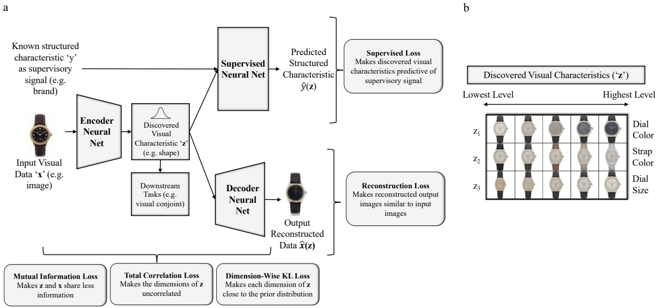
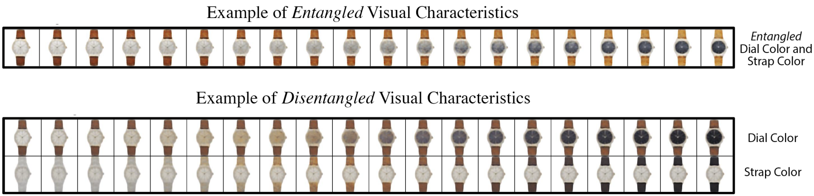
Hyundai: $(3, 8, 5, 9)$ compared to BMW: $(1, 3, 10, 1)$

Disentanglement → Visual Characteristics



Sisodia, A., Burnap, A., & Kumar, V. (2024). Generative Interpretable Visual Design: Using Disentanglement for Visual Conjoint Analysis. *Journal of Marketing Research*

Disentangled and Entangled Representations



Challenges in using visual images for market structure mapping

Three Challenges:

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    - We need to be able to choose what visual characteristics matter for market structure
    - Does color matter? Does angle matter?

Should Color be included in Visual Characteristics Maps?

- Should a red Ferrari California be close substitute to a red Toyota Corolla?

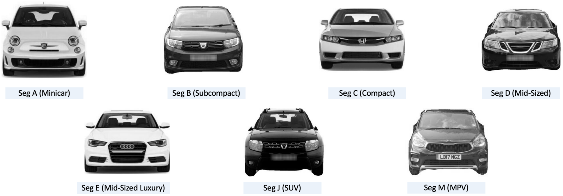
Data

- **UK Automobile Market**
  - 2,439 make-model-year observations from 2008 to 2017
  - 379 unique models from 49 unique makes
- **Sales and Auto Characteristics:**
  - Characteristics (price, MPG, horsepower, weight, dimensions, etc.) from Parker's
  - Sales from DVM-CAR[1]
- **Images:**
  - Front-facing automobile images from DVM-CAR
  - Converted from color to grayscale to *focus on shape* rather than color.
  - (very) Low-resolution: 128×128 pixels

[1] Huang, Jingmin, et al. (2022), *IEEE International Conference on Big Data*

Segments in the UK automobile market

Segment	Descriptio
A	Minicars
B	(Subcompac
C	Compact
D	Mid-size
E	Mid-size Lux
J	SUV
M	MPV



Summary Statistics of the 2013 UK Auto Market

Variable	**Mean**	**St. Dev.**	**Min.**	**Max.**
Total Quantity Sold	8,074.834	13,714.100	1	113,390
Price (in £000 units)	26.333	14.668	7.868	108.624
MPG (tens of miles per gallon)	4.999	1.058	2.250	7.200
Weight (in 10 lbs)	327.704	2.444	324.506	332.106
HP/Wt (in HP per 10 lbs.)	0.461	0.169	0.060	1.347
Length (in 1000 inches)	1.724	0.178	1.062	2.054
Width (in 1000 inches)	0.756	0.063	0.580	0.899
Height (in 1000 inches)	0.616	0.054	0.537	0.780
Wheelbase (in 1000 inches)	1.046	0.081	0.735	1.266
Space (length $\times$ width)	1.310	0.215	0.697	1.759
Vehicle Segment (Proportion):				
Segment A (Minicars)	0.112	0.316	0	1
Segment B (Subcompact)	0.120	0.326	0	1
Segment C (Compact)	0.162	0.369	0	1
Segment D (Mid-Size)	0.129	0.335	0	1
Segment E (Mid-Size Luxury)	0.071	0.257	0	1
Segment J (SUV)	0.241	0.428	0	1
Segment M (MPV)	0.166	0.373	0	1
Country of Origin (Proportion):				
France	0.108	0.311	0	1
Germany	0.241	0.428	0	1
Japan	0.220	0.415	0	1
South Korea	0.091	0.289	0	1
UK	0.108	0.311	0	1
USA	0.058	0.234	0	1

Match each model with front-facing image

Is this sufficient?

“Market research studies have shown that 70% of consumers identify and judge automobiles by the appearance of headlights and grille located on the face of the automobile.”

– The Wall Street Journal 2006

Loss Function & Supervisory Signals

$$\underbrace{L(\theta, \phi; \mathbf{m}, \mathbf{v})}_{\text{Disentanglement Loss}} = \underbrace{-\mathbf{E}_{q_\phi(\mathbf{v}|\mathbf{m})}\left[\log p_\theta(\mathbf{m}|\mathbf{v})\right]}_{\text{Reconstruction Loss}} + \underbrace{I_q(\mathbf{v}, \mathbf{m})}_{\text{Mutual Information Loss}} \tag{1}$$
$$+ \lambda_1 \underbrace{KL\left[q(\mathbf{v}) || \prod_{j=1}^{J} q(v_j)\right]}_{\text{Total Correlation Loss}} + \underbrace{\sum_{j=1}^{J} KL\left[q(v_j)||p(v_j)\right]}_{\text{Dimension-Wise KL Divergence Loss}} + \lambda_2 \underbrace{P(\widehat{\mathbf{y}(\mathbf{v})}, \mathbf{y})}_{\text{Supervised Loss}}$$

Number of Signals	Supervisory Signals	λ_1	λ_2	UDR
3	Wheelbase, Width, Height	50	10	0.739
3	HP/Weight, MPG, Space	50	30	0.710
1	Price	50	30	0.708
1	Weight	50	40	0.708
1	Wheelbase	50	30	0.690
1	Width	50	5	0.689
3	Length, Width, Height	50	40	0.678
1	Length	50	40	0.666
0	Unsupervised β-TCVAE	50	0	0.658
1	Height	30	20	0.378
1	Country of Origin	10	10	0.139
1	Segment	10	10	0.134
1	Unsupervised VAE	1	0	0.073
1	Unsupervised AE	0	0	0.074
1	Make	1	1	0.072

$\lambda_1 \in [1, 5, 10, 20, 30, 40, 50]$ and $\lambda_2 \in [0, 1, 5, 10, 20, 30, 40, 50]$.

Visual Characteristic 1: Body Shape

Body Shape
HATCHBACK

Body Shape
SEDAN

Correlation Between Discovered Visual Dimensions and Physical Vehicle Measures

	Wheelbase	Weight	Length	Height	Width	Height/Width Ratio
Body Shape	0.30	0.33	0.39	-0.28	0.25	-0.42

- Hatchback-like profiles → smaller wheelbase, lower length, and lighter
- Hatchback-like profiles → taller and narrower

Visual Characteristic 2: Boxiness

Boxiness
HIGH DEGREE

Boxiness
LOW DEGREE

Correlation Between Discovered Visual Dimensions and Physical Vehicle Measures

	Wheelbase	Weight	Length	Height	Width	Height/Width Ratio
Boxiness	0.05	-0.07	0.14	-0.59	0.02	-0.49

- Higher degree of boxiness → Taller and upfront from the front
- Lower degree of boxiness → Flatter and sleeker
- Boxiness captures cabin "uprightness" (not related to length or wheelbase)

Visual Characteristic 3: Grille Height

Correlation Between Discovered Visual Dimensions and Physical Vehicle Measures

	Wheelbase	Weight	Length	Height	Width	Height/Width Ratio
Grille Height	0.04	0.02	0.05	-0.04	0.03	-0.05

- Reflects stylistic design choices
- Unrelated to size-related factors

Visual Characteristic 4: Grille Width

Correlation Between Discovered Visual Dimensions and Physical Vehicle Measures

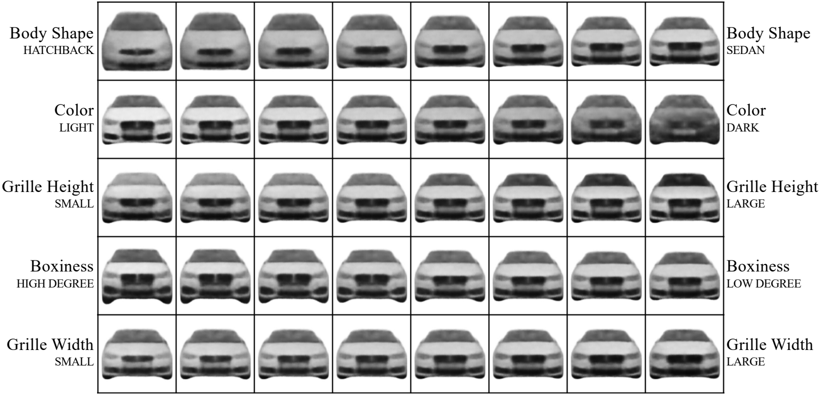
	Wheelbase	Weight	Length	Height	Width	Height/Width Ratio
Grille Width	0.12	0.08	0.12	0.03	0.15	-0.09

- Reflects stylistic design choices
- Unrelated to size-related factors

Visual Characteristic 5: Color

- We find the visual characteristic of *Color*.
- Color should not impact market structure because a car is available in many colors.
- We, therefore, exclude it when we create market structure maps.
- This is only possible because of disentanglement.

Disentanglement obtains four interpretable visual characteristics



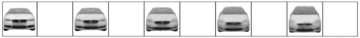
Left to Right: Vary one visual characteristic, keeping all others fixed

Human Understanding of Visual Characteristics

- Showed respondents sequence of car images

Q1/4: Look at the below image to see the various parts of a car.

Now, carefully examine each car image below from 1 to 5, going from left to right.
Note: Images are low-quality on purpose. Be sure to see all the images 1 to 5.



1 2 3 4 5

LEFT RIGHT

How does the car change the <u>most</u> as you go from image 1 to 5? Go through each part of the car one by one before deciding your response. Write it in a few words.

Human Understanding of Visual Characteristics

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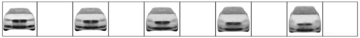

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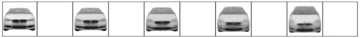

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- Example: LLM summarizes that respondents are saying that cars becoming lower, flatter, and wider can be thought of as boxiness

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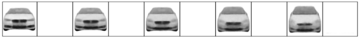

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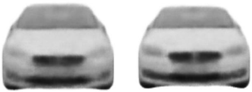
Quantification Validation Survey Question

Which pair of cars in your judgment are visually more similar? Carefully check both large and small visual aspects. Do not consider any non-visual features like brand or price.



Left Pair

Right Pair

Correlation Between Different Characteristics

	Functional Characteristics				Visual Characteristics			
	Price	MPG	HP/Weight	Space	Boxiness	Body Shape	Grille Height	Grille Width
Price	1.00							
MPG	-0.60	1.00						
HP/Weight	0.74	-0.48	1.00					
Space	0.67	-0.47	0.36	1.00				
Boxiness	0.06	0.04	0.29	0.09	1.00			
Body Shape	0.50	-0.25	0.54	0.36	0.13	1.00		
Grille Height	0.11	0.03	0.12	0.05	0.04	-0.02	1.00	
Grille Width	0.07	-0.05	0.04	0.15	0.01	-0.12	-0.05	1.00

Does Form Follow Function? Insight 1: Products close in functional space are differentiated visually

- *Operationalization*: Calculate correlation between distances in functional product characteristics and visual product characteristics for each pair of make-models within each segment

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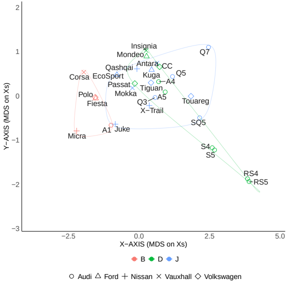
Segment	Correlation	Std. Error
A (Minicars)	-0.08	0.05
B (Subcompact)	-0.05	0.05
C (Compact)	-0.05	0.04
D (Mid-size)	0.02	0.04
E (Mid-size Luxury)	0.13	0.10
J (SUV)	0.09	0.03
M (MPV)	0.11	0.04

Market Structure Maps

Market Structure Map using only functional characteristics

Segment	Description
B	Subcompact
D	Mid-size
J	SUV



Market Structure Map using only visual characteristics

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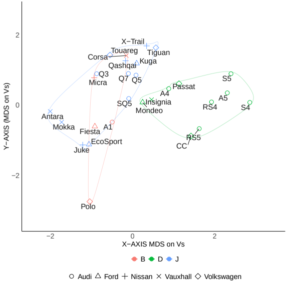
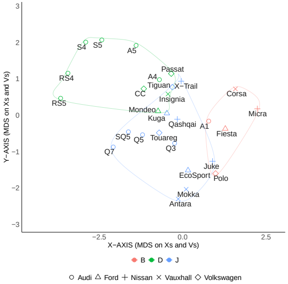
D	Mid-size
J	SUV



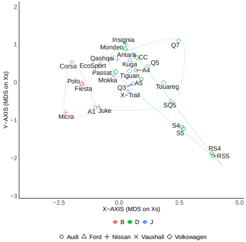
Market Structure Map using both type of characteristics

Segment	Description
B	Subcompact
D	Mid-size
J	SUV



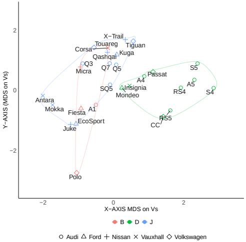
Insight 2: Visual increases differentiation and helps separate segments

Only Functional Characteristics



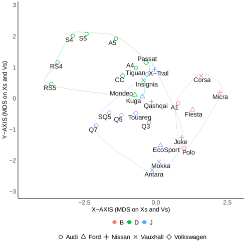
24.3% segment overlap

Only Visual Characteristics



32.9% segment overlap

Both Characteristics

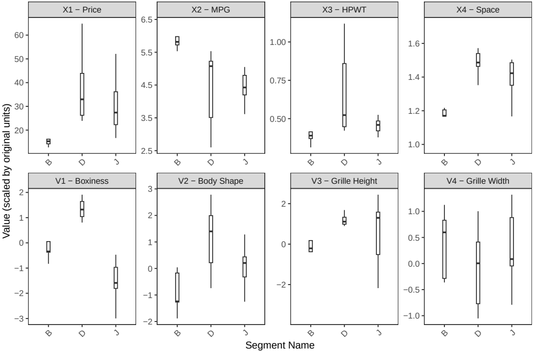


8.3% segment overlap

Does Disentanglement Provide Further Insights?

Insight 2D: Which visual characteristics increase differentiation?

- Disentanglement identifies interpretable characteristics contributing to differentiation



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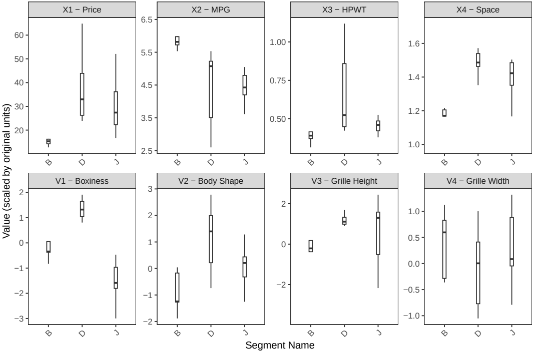
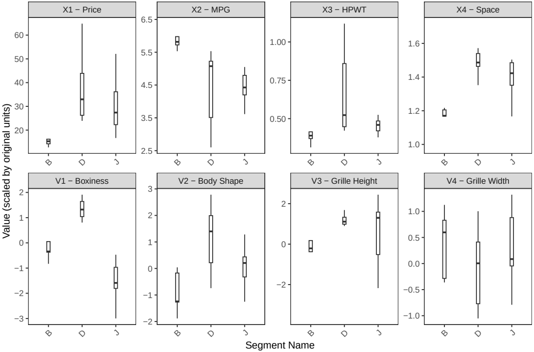


Insight 2**D**: Which visual characteristics increase differentiation?

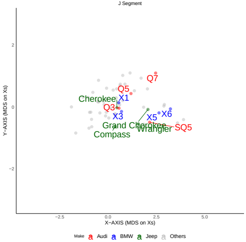
- Disentanglement identifies interpretable characteristics contributing to differentiation
- Seg D & J overlap on most of the functional characteristics but Seg B is different
- Seg D & J are different in boxiness and grille



Insight 3: Different Visual Strategy Across Brands

Segment J – SUVs

Only Functional Characteristics



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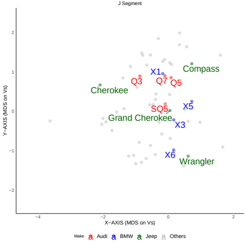

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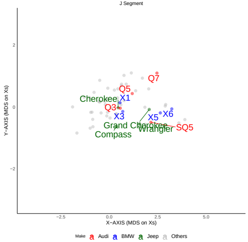

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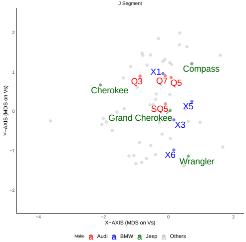


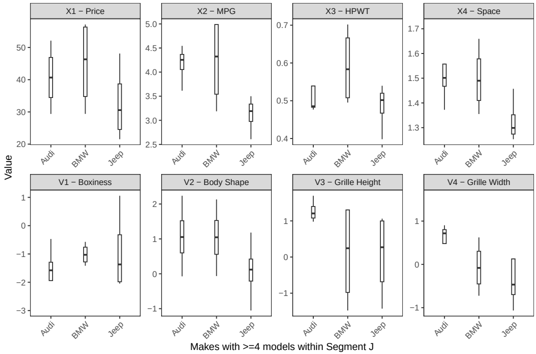
Area Share of a Make in Functional Space & Visual Space (Segment J: SUVs)

Make	Models	Area Share (Functional)	Area Share (Visual)	Ratio
Audi	4	17.90%	2.96%	6.05
BMW	4	6.35%	6.48%	0.98
Jeep	4	9.38%	28.42%	0.33

Insight 3D: Different Visual Strategy Across Brands

Disentanglement identifies interpretable characteristics

- Audi is very tight on some visual characteristics, notably, grille height and grille width $\implies$ *distinctive look*



Insight 3D: Different Visual Strategy Across Brands

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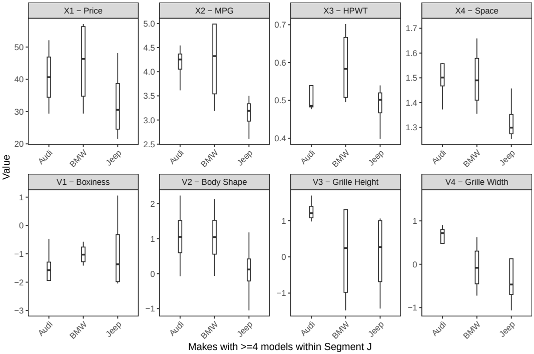

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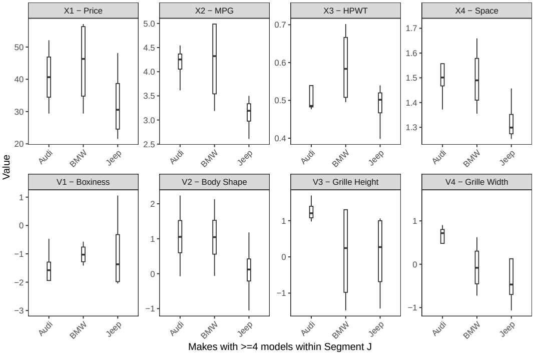
- Jeep varies on most visual characteristics



Insight 3: Different Visual Strategy Across Brands

Audi Q3

Audi Q5

Audi Q7

Audi SQ5

BMW X1

BMW X3

BMW X5

BMW X6

Jeep Cherokee

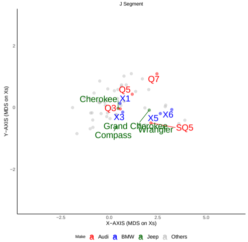
Jeep Compass

Jeep Grand Cherokee

Jeep Wrangler

Insight 4: Product-Level

Only Functional Characteristics



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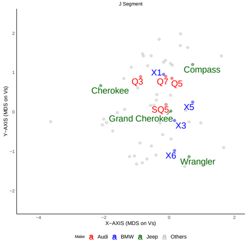

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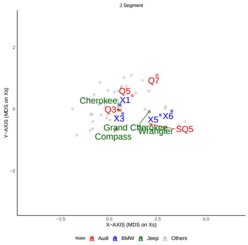

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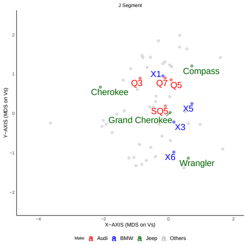

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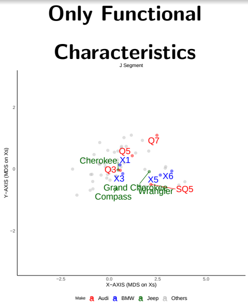

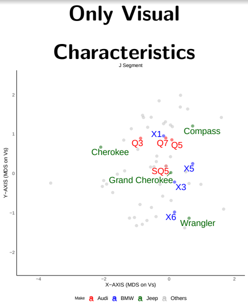

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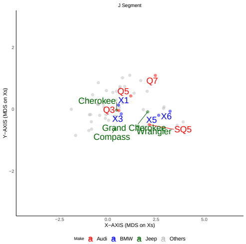

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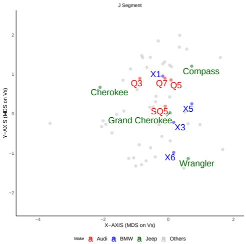

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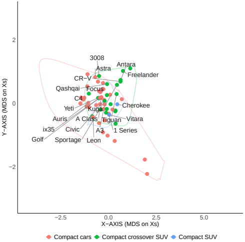
  - Visual map suggests the Grand Cherokee is closer instead

Insight 5: Leaping to Another Category

Only Functional Characteristics



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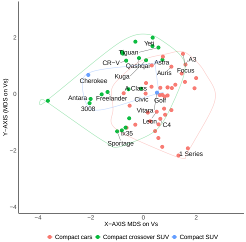
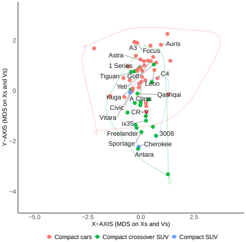
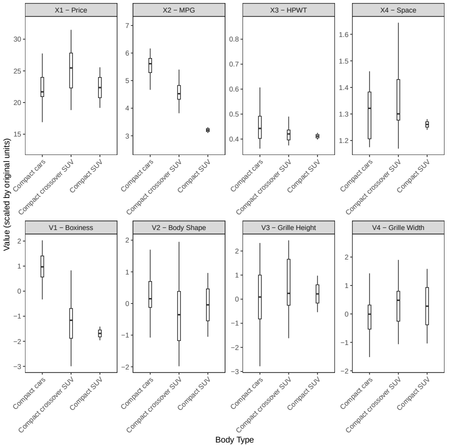


Both Characteristics



Insight 5D: Leaping to Another Category

- Compact cars and compact crossover SUVs differ in boxiness
- Compact cars and compact crossover SUVs overlap across most functional characteristics
- Compact crossover SUVs and compact SUVs are similar in visual characteristics
- Compact crossover SUVs and compact SUVs differ in some



Connecting Consumer Search to Market Structure Maps

Consumer Search $\Longleftrightarrow$ Market structure maps?

We use Google Trends to look for consumers searching pairs of models

- Consumer searching for "Honda Civic" and "Toyota Corolla" more likely to be comparing

$$\log_{10}(Y_{AB}+1) = \beta_0 + \beta_1(|X_A - X_B|) + \beta_2(|V_A - V_B|) + \epsilon_{AB}$$

[2] Raw Google Trend values are scaled by each pair's segment sales share

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Consumer Search $\Longleftrightarrow$ Market structure maps?

	(1)	(2)	(3)	(4)
Constant	2.778^{***}	9.509^{***}	2.974^{***}	8.871^{***}
	(0.205)	(1.425)	(0.291)	(1.479)
Δ HP/Weight	-2.395	-3.761^{**}	-2.886^{*}	-4.021^{***}
	(1.691)	(1.460)	(1.638)	(1.453)
Δ Space	-1.685	1.200	-1.444	1.431^{*}
	(1.068)	(0.851)	(1.031)	(0.853)
Δ MPG	-0.601^{***}	-0.407^{**}	-0.599^{***}	-0.432^{***}
	(0.199)	(0.163)	(0.196)	(0.165)
Δ Price	-0.214^{***}	-0.188^{***}	-0.203^{***}	-0.194^{***}
	(0.037)	(0.031)	(0.036)	(0.032)
Δ Boxiness			-0.263	0.249
			(0.161)	(0.154)
Δ Bodyshape			0.149	-0.361^{**}
			(0.108)	(0.144)
Δ Grille Height			-0.284^{***}	-0.007
			(0.072)	(0.065)
Δ Grille Width			0.324^{**}	-0.001
			(0.138)	(0.145)
Make Fixed Effects	No	Yes	No	Yes
Observations	306	306	306	306
R^2	0.168	0.590	0.247	0.602
Adjusted R^2	0.157	0.559	0.227	0.566

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Consumers search for visually similar cars even after accounting for functional similarity

Conclusion and Takeaways

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