

# Hedonic Pricing of Vehicle Characteristics, Safety and Equipment in the UK Car Market

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# Motivation

- The car market is entering a unique stage of transformation, where the focus on **environmentally friendly vehicles** is greater than ever.
- UK has one of the largest car markets in the world (6<sup>th</sup>), with a growing share of alternative fuel vehicles (AFVs), and a great importance to the UK economy.
- However, extensive and contemporary insight into the vehicle characteristics that influence prices is lacking.
- Therefore, the purpose of this paper is to provide this insight, using a **large, unique, and current dataset**, and applying the **hedonic pricing** technique with **quantile regressions**.
- To the best of my knowledge, no study has done an analysis for the UK car market with such an extensive and recent dataset, while applying quantile regressions.

# Research Questions

- The study aims to provide an insight into the drivers of prices in the UK car market by focusing on the following research questions:
  - **Question 1:** What are the key car characteristics, features, and equipment that influence UK vehicle prices?
  - **Question 2:** How does this influence differ between conventional vehicles (CVs) and AFVs?
  - **Question 3:** Constructing the quality adjusted hedonic price indices, to disentangle price change into quality growth and other factors.
- The questions above may be of interest to many car dealers attempting to set competitive prices, as well as to the government and policy makers in general.

- The research paper constructs and uses a completely **new, manually collected dataset**, from a wide range of sources, both physical and online.
- Sources of the collected information include: Society of Motor Manufacturers and Traders (SMMT), MarkLines portal, Auto Express, Parkers database, Euro NCAP, etc.
- This includes a wide range of **vehicle physical characteristics, safety features, equipment, sale figures** and **prices**, for almost all car models in the UK market, in 2008-2019.
- The dataset contains 3017 observations, 67 different vehicle characteristics, and 144 different constructed variables.
- All variables were **standardized** to mean 0 and standard deviation 1, to make the regression coefficients directly comparable.

# Methodology: Hedonic Modelling

- The main model applied to the data is a **semi-logarithmic hedonic pricing model**, which is used to derive prices of various characteristics that make up a composite good, such as a car.
- The utility is not derived from the composite good, but rather from the good's many different characteristics. Hedonic pricing regressions attempt to estimate these prices.
- Using the heteroskedasticity robust **RESET test** to identify the optimal functional form as semi-logarithmic, the hedonic model applied is:

$$\ln P_j = \beta_0 + \sum_{t=1}^T \beta_t d_{j,t} + \sum_{i=1}^I \beta_i z_{j,i} + \epsilon_j, \quad j = 1, 2, \dots, n$$

$P_j$  = price of car model  $j$

$d_{j,t}$  = dummy equal to 1 if car model  $j$  was in the market in the year  $t$

$z_{j,i}$  = value of characteristic  $i$  for model  $j$

$\beta_i, \beta_t$  = coefficients

$\epsilon_j$  = error term

$T$  = number of time periods

$I$  = number of car characteristic

# Methodology: Adaptive Lasso

- The **Adaptive Lasso** technique is run before each regression, in order to reduce multicollinearity and for variable selection:

$$\hat{\beta}_n^{AL} = \arg \min_u \sum_{j=1}^n (y_j - u'x_j)^2 + \lambda_n \sum_{i=1}^p \lambda_{n,i} |u_i|$$

$\lambda_n > 0$  = tuning parameter

$\lambda_{n,i} = \frac{1}{(|\hat{\beta}_{n,i}|)^\gamma}$  = adaptive weights vector

$\hat{\beta}_{n,i}$  = initial estimate of the coefficients

$\gamma$  = positive constant for adjustment of the adaptive weights vector, set between  $\frac{1}{3}$  and  $\frac{10}{3}$ .

$u_i$  = estimated coefficients

- The method shrinks the coefficient of those variables that are irrelevant for the research to zero.
  - Most important is the **tuning parameter**  $\lambda_n$ , found using 10 rounds of cross-validation.
  - Compared to standard Lasso, Ad. Lasso is **less sensitive** to outliers and choice of the tuning parameter.
- Following the identification of key variables using the Adaptive Lasso, the **ordinary least squares, weighted least squares, quantile, and weighted quantile** regressions are applied, separately to CVs and AFVs.

# Methodology: Hedonic Indices

- Following the regressions, three different **hedonic price indices** are constructed for the UK car market.
  - These include: the hedonic **Laspeyres** Index, hedonic **Paasche** Index, and hedonic **Fisher** Index.
- Hedonic price indices are superior to standard price indices in several ways:
  - They consider even **missing car models** – those models that left or entered the market during the period examined (2008 – 2019).
  - They account for changing quality of the vehicles – i.e., they are **quality constant**.
  - They allow for disentangling growth of prices into quality change, and other factors.
- Prices of the **missing car models** are **imputed** (estimated) using hedonic regressions of prices on vehicle characteristics.

# Results: Regressions



Dep Var: Ln Price	OLS		WLS	
<b>Car Characteristics</b>				
Diesel Engine	0.069***	(0,013)	-0,003	(0,015)
AFV	0.179***	(0,034)	0,147***	(0,035)
Displacement	0.010	(0,015)	-0,003	(0,015)
Engine Power	0.186***	(0,016)	0,156***	(0,021)
Maximum Speed	0.047**	(0,019)	0,036*	(0,021)
Acceleration	0.007	(0,012)	-0,026*	(0,014)
Interior Noise	-0.010	(0,008)	-0,016*	(0,008)
CO <sub>2</sub> Emissions	-0.093***	(0,016)	0,008	(0,024)
Maximum Range	-0.091***	(0,008)	-0,001	(0,015)
Size	0.048***	(0,015)	0,033**	(0,017)
Number of Doors	-0.023***	(0,005)	-0,025***	(0,006)
Trunk Capacity	0.009**	(0,004)	0,028***	(0,006)
Fuel Tank Capacity	0.065***	(0,007)	-0,005	(0,019)
Curb Weight	0.118***	(0,015)	0,137***	(0,021)
<b>Safety</b>				
NCAP Average Rating	0.009*	(0,005)	0,023***	(0,006)
Airbags per Seat	0.021***	(0,006)	0,031***	(0,006)
Pretensioners per Seat	-0.014**	(0,006)	-0,017**	(0,007)
Loadlimiters per Seat	-0.010*	(0,006)	-0,015*	(0,007)
<b>Equipment</b>				
Traction Control	0.053***	(0,013)	0,022	(0,017)
Hill Start Assist	-0.019**	(0,008)	-0,017**	(0,008)
Deflation Warning	-0.002	(0,008)	0,008	(0,010)
Collision Warning	-0.055***	(0,011)	-0,017	(0,013)
Traffic Sign Recognition	-0.039**	(0,018)	-0,014	(0,016)
Lane Assist	0.007	(0,010)	0,004	(0,011)
Display	0.023***	(0,008)	0,033***	(0,009)
Auto Air Conditioning	0.012	(0,012)	0,072***	(0,013)
Electric Mirrors	0.048***	(0,016)	0,059***	(0,016)
Heated Mirrors	0.002	(0,013)	-0,001	(0,014)
Heated Steering Wheel	-0.002	(0,014)	0,016	(0,012)
Automatic Wipers	0.025**	(0,011)	0,055***	(0,012)
Automatic Lights	-0.013	(0,010)	-0,014	(0,010)
Radio	0.090***	(0,027)	0,031	(0,024)
Number of Speakers	0.030***	(0,006)	0,013*	(0,007)
Remote Audio Control	-0.002	(0,010)	-0,022**	(0,011)
USB Jack	-0.014*	(0,008)	-0,013	(0,009)
Parking Sensors	0.036***	(0,012)	0,022**	(0,010)
Rear View Camera	0.043***	(0,010)	0,035***	(0,010)
Heated Seats	0.006	(0,011)	-0,013	(0,012)
<b>Time Dummies</b>	<b>Yes</b>		<b>Yes</b>	
<b>Segment Dummies</b>	<b>Yes</b>		<b>Yes</b>	
<b>Country Dummies</b>	<b>Yes</b>		<b>Yes</b>	
<b>R-squared</b>	<b>0.9225</b>		<b>0.9369</b>	

- The results indicate that the main drivers of UK car prices include:
  - **Performance** (measured by engine power, maximum speed and acceleration).
  - **Size/massiveness** (measured by weight and car size).
- Most important equipment includes **auto AC, electric mirrors, and auto wipers.**
- AFV prices are found to be significantly more sensitive to changes in features compared to CV prices, especially in relation to **performance, emissions and extra equipment.**

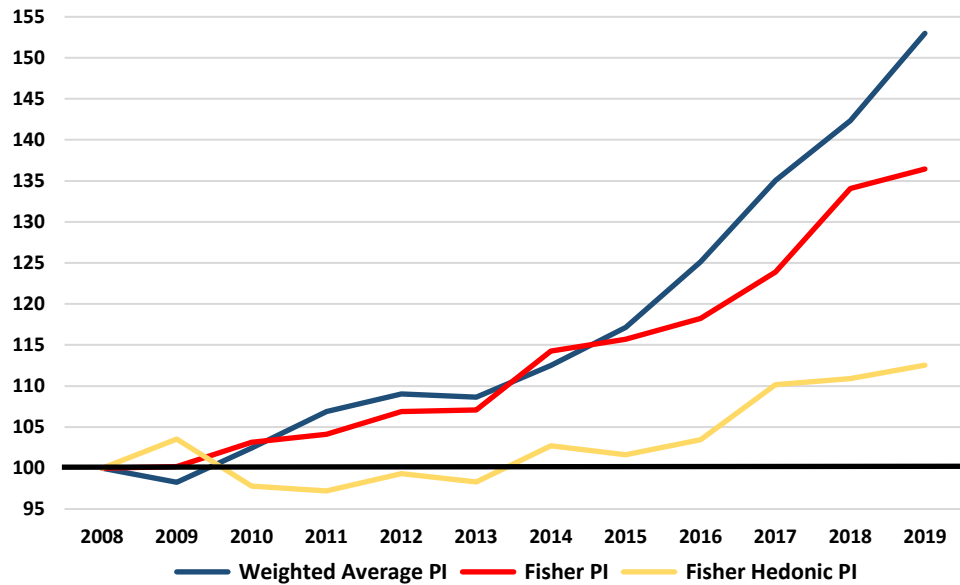


# Results: Q. Reg.



Variable	WLS		Weighted (Penalized) Quantile Regression								
			0.10		0.25		0.50		0.75		0.90
Car Characteristics	Diesel Engine	-0.003 (0.015)	-0.036** (0.018)	-0.013 (0.012)	0.008 (0.012)	-0.016 (0.018)	-0.012 (0.019)				
	Alternative Fuel Vehicle	0.147*** (0.035)	0.120*** (0.046)	0.078*** (0.030)	0.114** (0.048)	0.168*** (0.037)	0.166*** (0.040)				
	Displacement	-0.003 (0.015)	-0.009 (0.021)	0.007 (0.015)	-0.005 (0.013)	0.034** (0.015)	0.067** (0.029)				
	Engine Power	0.156*** (0.021)	0.085*** (0.030)	0.141*** (0.022)	0.167*** (0.020)	0.211*** (0.024)	0.222*** (0.026)				
	Maximum Speed	0.036* (0.021)	0.040 (0.040)	0.016 (0.017)	0.032* (0.016)	-0.019 (0.018)	-0.026 (0.025)				
	Acceleration	-0.026* (0.014)	-0.065*** (0.021)	-0.052*** (0.015)	-0.030*** (0.010)	-0.037*** (0.013)	-0.038* (0.022)				
	Interior Noise	-0.016* (0.008)	0.005 (0.012)	-0.002 (0.009)	-0.016** (0.007)	-0.009 (0.007)	-0.021 (0.014)				
	CO <sub>2</sub> Emissions	0.008 (0.024)	0.048 (0.031)	0.039* (0.022)	0.052** (0.022)	0.033 (0.020)	-0.021 (0.034)				
	Maximum Range	-0.001 (0.015)	0.033* (0.018)	0.025* (0.014)	0.028** (0.014)	0.020 (0.015)	-0.007 (0.022)				
	Size	0.033** (0.017)	0.029 (0.027)	0.034* (0.017)	0.031** (0.015)	0.045*** (0.015)	0.057*** (0.021)				
	Number of Doors	-0.025*** (0.006)	-0.010 (0.008)	-0.007 (0.005)	-0.012** (0.005)	-0.018*** (0.004)	-0.027*** (0.007)				
	Trunk Capacity	0.028*** (0.006)	0.043*** (0.009)	0.031*** (0.006)	0.012* (0.006)	0.020** (0.008)	0.023** (0.011)				
	Fuel Tank Capacity	-0.005 (0.019)	-0.039 (0.026)	-0.042** (0.017)	-0.048*** (0.016)	-0.025 (0.017)	-0.008 (0.027)				
	Curb Weight	0.137*** (0.021)	0.131*** (0.025)	0.112*** (0.021)	0.133*** (0.018)	0.161*** (0.022)	0.128*** (0.031)				
	Safety	NCAP Average Rating	0.023*** (0.006)	0.027*** (0.009)	0.027*** (0.005)	0.025*** (0.004)	0.021*** (0.005)	0.005 (0.008)			
Airbags per Seat		0.031*** (0.006)	0.011 (0.009)	0.018*** (0.006)	0.025*** (0.005)	0.037*** (0.006)	0.028*** (0.009)				
Pretensioners per Seat		-0.017** (0.007)	0.007 (0.008)	-0.017** (0.008)	-0.008 (0.005)	-0.008 (0.007)	-0.015 (0.011)				
Loadlimiters per Seat		-0.015* (0.007)	-0.023*** (0.008)	-0.014* (0.008)	-0.023*** (0.005)	-0.018*** (0.006)	-0.012 (0.010)				
Equipment	Traction Control	0.022 (0.017)	0.005 (0.021)	-0.001 (0.014)	0.012 (0.014)	0.008 (0.011)	0.005 (0.027)				
	Hill Start Assist	-0.017** (0.008)	0.009 (0.012)	-0.012 (0.009)	-0.014* (0.008)	-0.009 (0.009)	0.013 (0.011)				
	Deflation Warn. System	0.008 (0.010)	0.038*** (0.013)	0.027*** (0.009)	0.008 (0.009)	-0.004 (0.010)	-0.003 (0.011)				
	Forward Collision Warn.	-0.017 (0.013)	-0.049*** (0.016)	-0.038*** (0.014)	-0.020 (0.012)	0.005 (0.015)	-0.010 (0.019)				
	Traffic Sign Recognition	-0.014 (0.016)	0.030 (0.024)	0.035 (0.026)	0.007 (0.016)	-0.002 (0.021)	-0.025 (0.037)				
	Lane Assist	0.004 (0.011)	0.005 (0.016)	0.011 (0.016)	0.025** (0.010)	-0.007 (0.014)	0.026 (0.017)				
	Display	0.033*** (0.009)	0.051*** (0.012)	0.035*** (0.010)	0.019*** (0.007)	0.009 (0.008)	0.004 (0.017)				
	Auto Air Conditioning	0.072*** (0.013)	0.079*** (0.017)	0.092*** (0.014)	0.076*** (0.009)	0.056*** (0.014)	0.079*** (0.020)				
	Electric Mirrors	0.059*** (0.016)	0.064*** (0.025)	0.071*** (0.014)	0.083*** (0.016)	0.088*** (0.014)	0.075*** (0.020)				
	Heated Mirrors	-0.001 (0.014)	0.037* (0.020)	0.004 (0.014)	-0.019 (0.014)	-0.008 (0.012)	-0.015 (0.020)				
	Heated Steering Wheel	0.016 (0.012)	0.023 (0.018)	0.002 (0.015)	0.009 (0.011)	-0.008 (0.018)	-0.029 (0.018)				
	Automatic Wipers	0.055*** (0.012)	0.054*** (0.018)	0.045*** (0.014)	0.045*** (0.012)	0.044*** (0.013)	0.028 (0.018)				
	Automatic Lights	-0.014 (0.010)	-0.023 (0.014)	-0.028** (0.011)	0.001 (0.011)	0.008 (0.012)	0.006 (0.015)				
	Radio	0.031 (0.024)	-0.003 (0.044)	0.024 (0.024)	-0.007 (0.023)	0.031 (0.024)	0.114*** (0.033)				
	Number of Speakers	0.013* (0.007)	0.020** (0.008)	0.017** (0.007)	0.018*** (0.005)	0.009 (0.007)	0.006 (0.009)				
Remote Audio Control	-0.022** (0.011)	-0.028*** (0.010)	-0.023* (0.012)	-0.026*** (0.008)	-0.016 (0.010)	-0.013 (0.015)					
USB Jack	-0.013 (0.009)	0.002 (0.013)	0.006 (0.010)	-0.007 (0.006)	-0.020** (0.009)	-0.009 (0.015)					
Parking Sensors	0.022** (0.010)	0.029* (0.017)	0.029** (0.013)	0.017* (0.009)	0.044*** (0.013)	0.028 (0.018)					
Rear View Camera	0.035*** (0.010)	0.037*** (0.014)	0.026** (0.011)	0.019** (0.009)	0.031*** (0.010)	0.022 (0.018)					
Heated Seats	-0.013 (0.012)	0.026 (0.017)	0.009 (0.016)	-0.025*** (0.009)	-0.043*** (0.012)	-0.034** (0.016)					

- The QR results indicate significant **quantile effects** in the main price drivers: performance and size.
  - 8.9% at the 10<sup>th</sup>, 24.9% at the 90<sup>th</sup>.
- The effect of **performance** (power) is **stronger** for expensive cars.
  - No effect at 10<sup>th</sup>, 5.9% at the 90<sup>th</sup>.
- The effect of **size** also gets **stronger** as car price increases.
  - 9 significant at the 10<sup>th</sup>, 3 at the 90<sup>th</sup>.
- The effect of **equipment** gets **weaker** as cars get more expensive.
  - 9 significant at the 10<sup>th</sup>, 3 at the 90<sup>th</sup>.



# Results: Hed. Indices

- Hedonic price indices estimate the price change for all vehicle models – even those that disappeared from the market or were introduced after the base period.
- Thus, hedonic indices are **quality constant**, and show the evolution of prices unaffected by quality change.

Year	Standard Indices					Hedonic Indices		
	Average Price Index	Weighted Average Price Index	Laspeyres Price Index	Paasche Price Index	Fisher Price Index	Laspeyres Hedonic Price Index	Paasche Hedonic Price Index	Fisher Hedonic Price Index
2008	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2009	100.96	98.27	100.21	100.15	100.18	100.05	107.14	103.53
2010	107.55	102.42	103.71	102.57	103.14	94.57	101.17	97.82
2011	114.02	106.89	104.52	103.71	104.11	95.67	98.82	97.23
2012	115.23	109.04	108.01	105.79	106.89	98.76	99.85	99.30
2013	115.76	108.66	108.49	105.68	107.08	98.45	98.20	98.32
2014	120.60	112.50	116.67	111.91	114.26	106.51	99.08	102.73
2015	129.70	117.16	120.14	111.44	115.71	102.48	100.80	101.64
2016	137.20	125.13	120.75	115.81	118.26	104.85	102.10	103.47
2017	154.61	135.04	122.68	125.13	123.90	112.44	107.91	110.15
2018	161.21	142.34	135.02	133.16	134.09	111.45	110.39	110.92
2019	171.21	153.00	136.66	136.22	136.44	113.74	111.32	112.53

- The results suggest an annual price growth of 1.08% rather than 2.86%, if car quality stayed the same between 2008-2019.
- Consequently, about **65%** of the increase in car prices was caused by improvements in vehicle quality (about **2% per year**).

# Conclusion and Policy Relevance

- The results of the research and analysis can offer useful information to various parties.
- These may include dealers and manufacturers, aiming to optimize their competitive **pricing strategies**, while **increasing their sales**.
- Confirming the drivers of AFV prices can be of great use to the UK government, marketers, and manufacturers, looking to encourage the adoption of more **energy efficient vehicles**.
- More competitive pricing could lead to **higher AFV adoption rates**, which is high on the UK government policy goals, in relation to the planned banning new CV sales by 2030 and reaching net zero emissions by 2050.