Karlsruher Institut für Technologie

On the Analysis of Irrational Behavior in Car Configuration Data.

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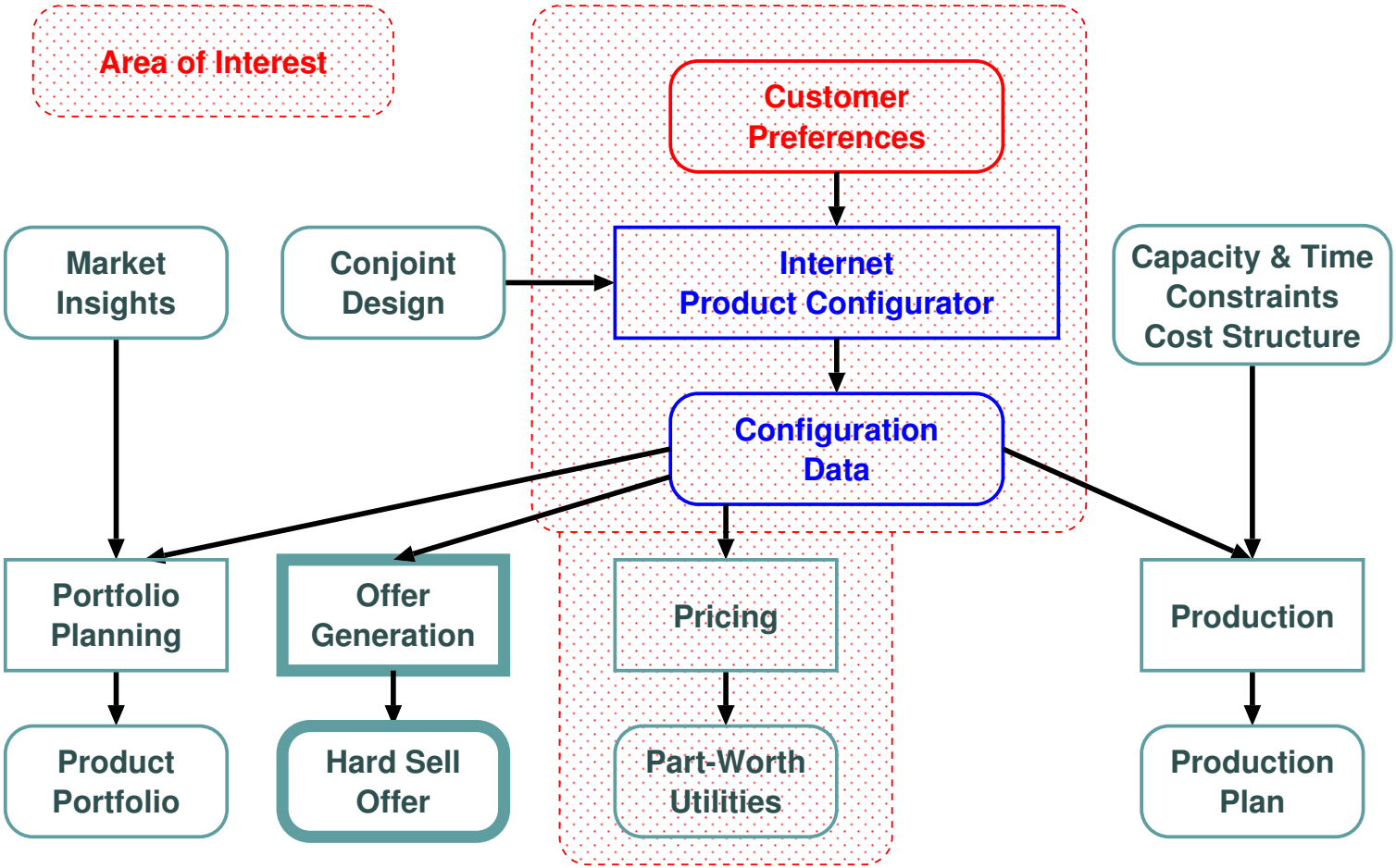
Content

Product Configurators: Definition

A product configurator is a software-based expert system that supports the user in the creation of product specifications by restricting how predefined entities (physical or non-physical) and their properties (fixed or variable) may be combined.
[Haug, 2007, p. 19]

Product Configurators: The Big Picture

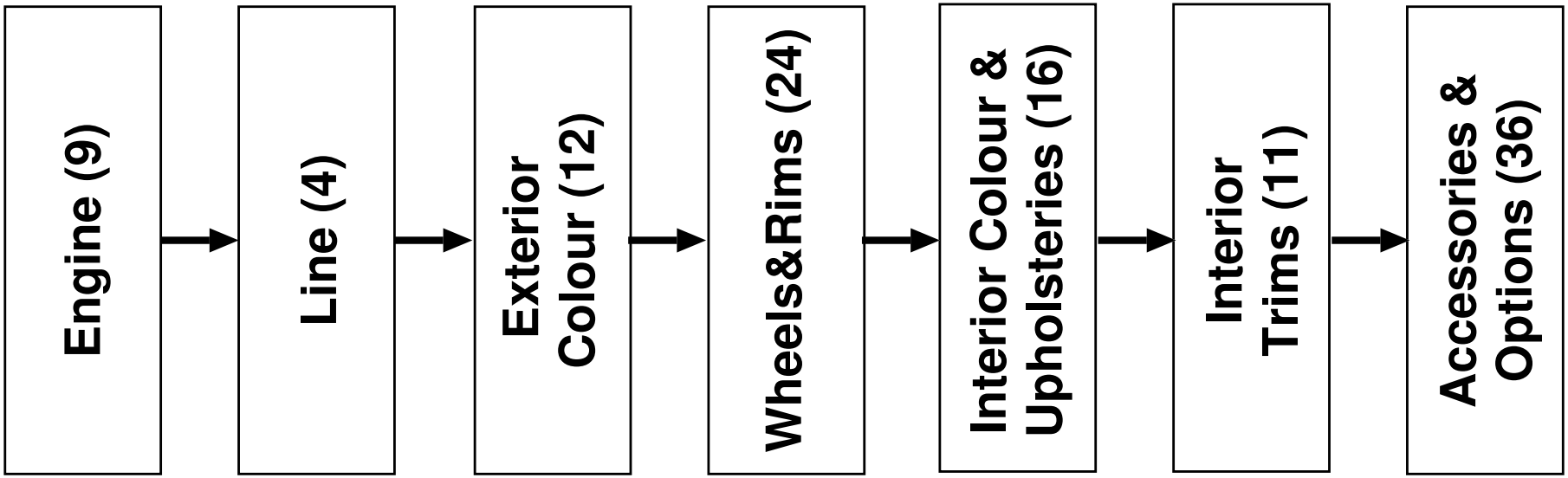


1 Motivation

1. Global competition $\Rightarrow$ Mass customization at industrial scale [Pine, 1999]:
   The customer should get what he wants, when he wants it at an attractive price.
2. The end consumer must be enabled to autonomously **build his own product (BYO)**
   – even, if the product is complex.
3. TNS Infratest provided a large car configuration data set (almost a million car configurations out of 60 million).
4. **Today:** We want to extract a linear part-worth function for the attributes of the car configurator.

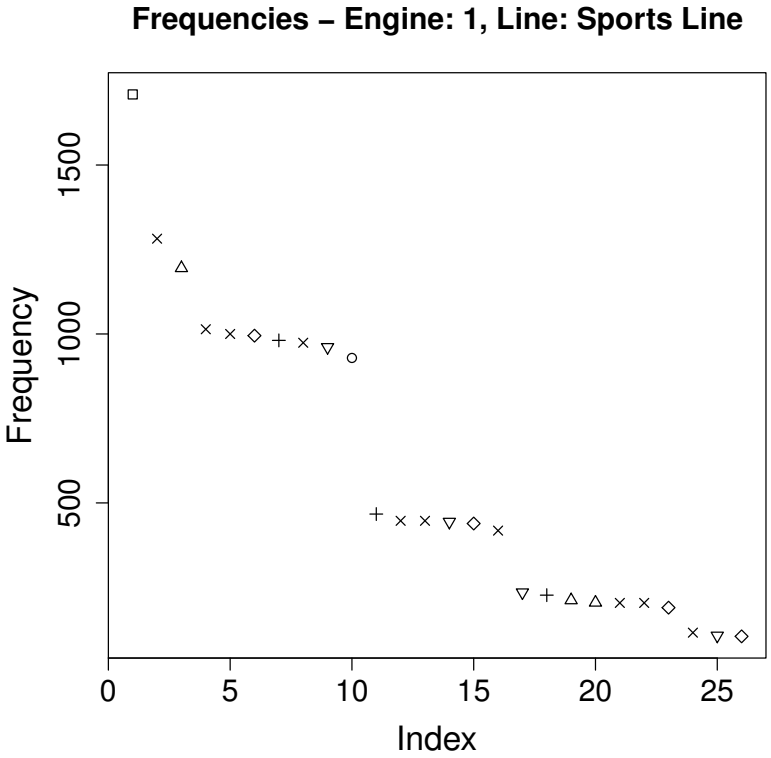
Rational pricing of configurations?

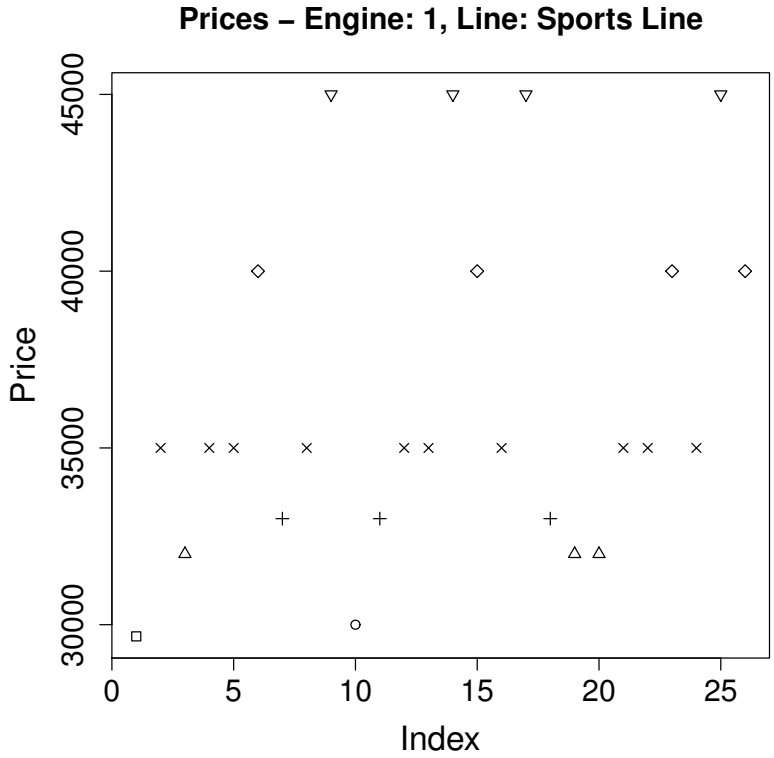
The Product Configuration Process



- Engine and line selections influence available attribute choices in the following steps.
- Configuration dependencies are not documented and have to be inferred from the data set.

The Discovery of Iso-Price Segments





The segment **Sports Line** with **Engine 1**

The Discovery of Iso-Price Segments I

Model Line	No Line	Sports	Luxury	Modern
Engine 1: No. of Conf. Types (Max)	50 (12)	26 (10)	4 (3)	24 (7)
No. of Cars Configured	53773	28908	7156	27982
Price Average (Euro)	33870	35269	33604	35864
Price Range (in 1000 Euro)(Levels)	20-55 (10)	29-45 (7)	31-35 (2)	28-55 (9)
Value (in Mio Euro)	854	546	143	445
Engine 2: No. of Conf. Types (Max)	49 (9)	87 (23)	43 (11)	44 (9)
No. of Cars Configured	48999	89675	40532	41566
Price Average (Euro)	37633	39134	37672	38122
Price Range (in 1000 Euro)(Levels)	28-47 (14)	35-45 (10)	28-45 (9)	34-45 (11)
Value (in Mio Euro)	770	1885	781	714
Engine 3: No. of Conf. Types (Max)	15 (6)	61 (7)	9 (4)	9 (4)
No. of Cars Configured	13479	60977	9252	10910
Price Average (Euro)	42556	47426	46452	45154
Price Range (in 1000 Euro)(Levels)	40-46 (4)	38-83 (13)	40-55 (3)	40-50 (5)
Value (in Mio Euro)	219	1443	232	238

The Discovery of Iso-Price Segments II

Model Line	No Line	Sports	Luxury	Modern
Engine 4: No. of Conf. Types (Max)	- (-)	2 (2)	1 (1)	- (-)
No. of Cars Configured	-	1865	3639	-
Price Average (Euro)	-	45000	45500	-
Price Range (in 1000 Euro)(Levels)	- (-)	45-45 (1)	45-45 (1)	- (-)
Value (in Mio Euro)	-	64	80	-
Engine 5: No. of Conf. Types (Max)	37 (16)	51 (11)	11 (5)	9 (6)
No. of Cars Configured	37097	52270	11153	8033
Price Average (Euro)	35337	37558	36481	38019
Price Range (in 1000 Euro)(Levels)	28-40 (7)	34-45 (11)	34-40 (4)	32-40 (4)
Value (in Mio Euro)	597	1000	215	135
Engine 6: No. of Conf. Types (Max)	56 (15)	99 (31)	24 (8)	39 (13)
No. of Cars Configured	55179	101272	24991	37783
Price Average (Euro)	38716	40687	42093	39525
Price Range (in 1000 Euro)(Levels)	34-45 (11)	30-52 (14)	35-50 (9)	35-48 (9)
Value (in Mio Euro)	873	2041	468	884

The Discovery of Iso-Price Segments III

Model Line	No Line	Sports	Luxury	Modern
Engine 7: No. of Conf. Types (Max)	24 (10)	39 (11)	18 (16)	17 (9)
No. of Cars Configured	23476	42913	18020	17456
Price Average (Euro)	43583	42805	43944	45168
Price Range (in 1000 Euro)(Levels)	39-50 (5)	38-50 (9)	40-45 (2)	40-50 (4)
Value (in Mio Euro)	464	867	362	460
Engine 8: No. of Conf. Types (Max)	12 (3)	34 (7)	2 (1)	12 (4)
No. of Cars Configured	10510	34578	1721	11054
Price Average (Euro)	50192	52582	54371	63145
Price Range (in 1000 Euro)(Levels)	48-55 (6)	47-62 (11)	53-55 (2)	50-94 (5)
Value (in Mio Euro)	146	938	17	440
Engine 9: No. of Conf. Types (Max)	3 (2)	17 (5)	8 (4)	7 (4)
No. of Cars Configured	3662	18359	8172	6387
Price Average (Euro)	57433	63094	57061	50682
Price Range (in 1000 Euro)(Levels)	55-65 (2)	47-96 (5)	50-65 (3)	45-96 (3)
Value (in Mio Euro)	58	632	202	158

The Discovery of Iso-Price Segments IV

- 175 out of the 225 iso price segments contain more than one configuration.
- The number of different configurations is low: 31.
- A formal concept analysis of configurations in an iso price segment is feasible and visualizes the structure of common attributes.

The Axioms of Utility Theory

Axiom 1: For any two actions x and y in a set of actions A with uncertain consequences, a decision-maker always prefers x to y ($x \succ y$) or y to x ($y \succ x$) or is indifferent ($y \sim x$) (Completeness).
Axiom 2: For any three actions x, y, and z if a decision-maker prefers x to y ($x \succ y$) and y to z ($y \succ z$), then he also prefers x to z ($x \succ z$). For indifference, if $x \sim y$ and $y \sim z$, then $x \sim z$. (Transitivity or Consistency).

The Axioms of Utility Theory

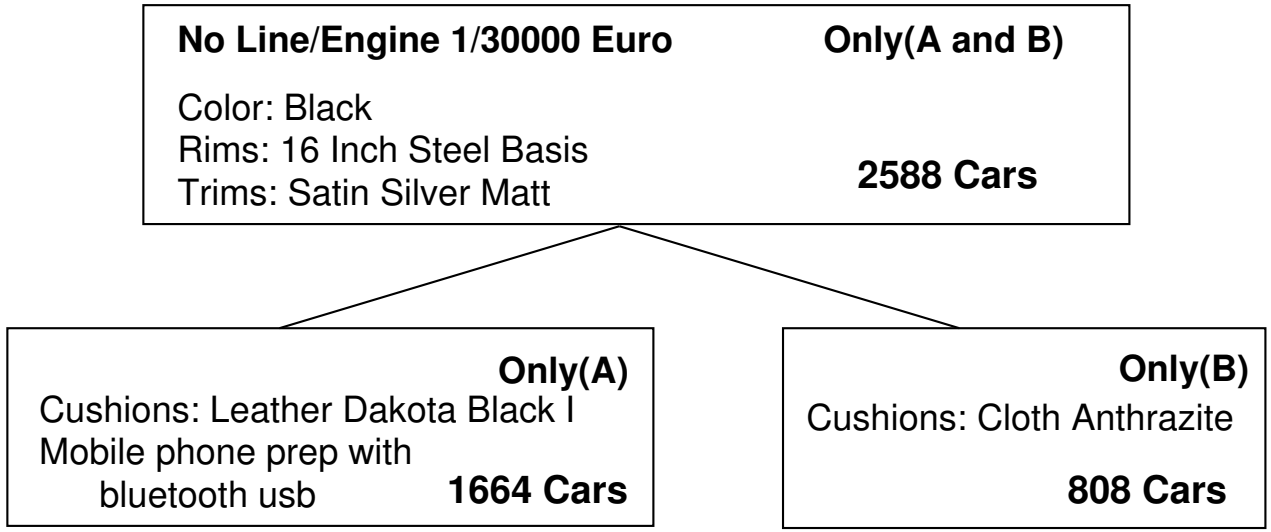
Axiom 3: $L(x, z : \alpha)$ denotes a lottery whose payoff is x with probability α and z with probability $1 - \alpha$. If $x \sim y$, then $L(x, z : \alpha) \sim L(y, z : \alpha)$ (Strong Independence or Substitution).
Axiom 4: If $x \succ y \succeq z$ or $x \succeq y \succ z$, then a probability α exists that $y \sim L(x, z : \alpha)$ (Measurability or Continuity).
Axiom 5: If the actions y and u both are between the actions x and z with $x \prec z$, two lotteries exist which have the property that $y \sim L(x, z : \alpha_1)$ and $u \sim L(x, z : \alpha_2)$. If $\alpha_1 < \alpha_2$, then $y \succ u$ (Rank Order).
Axiom 6: More "wealth" is always preferred to less "wealth" (Non-Satisfiability).
See John von Neumann and Oskar Morgenstern (1944) [Morgenstern and Neumann, 1990, Chapter 3, pp. 15-31]

Assumptions on Car Configurations

We assume that the payoff of choosing a car configuration is defined by the configuration price.
For simplicity, we further assume that the utility of a car configuration is described by a linear (part-worth) utility function
$U(C) = w_0 + \sum_{c_i \in C} w_i \cdot c_i$ where w_0 is the base price of the configuration, C denotes the set of attributes describing the configuration and $c_i \in \{0, 1\}$ the i-th attribute in C and w_i the part-worth of the i-th attribute.
For the first group of attributes (Color, Rims, Cushions, Trims) we know the part-worths from the experimental setup, but we do not use them.
For the second we do not know the part worths.
We assume that an attribute configured has a higher part worth than an attribute which is not configured (Axiom 6).
All part-worths should be positive: $w_i \geq 0, quad \forall i$.

Deviations from Rationality: Proper Subsets

Deviations from Rationality: Inferior Value of Attributes



- Leather cushions add 1750 Euro to the configuration price whereas cloth anthrazite is the standard configuration for cushions (additional price 0 Euro) and, therefore, does not change the price of the configuration.
- The mobile phone preparation provides additional value to the customer.

Is in the data. Not used.

Interesting Patterns in Iso-Price Segments

Patterns of Irrational Choice Behavior for Car Configurations:

- Configurations which are proper subsets of other configurations (To Be Continued ...).
- Configurations whose value (computed from known add-on prices for attributes) is lower than that of other configurations in the same iso-price segment (Not used).

Patterns of these types present in about 1/3 of all iso-price segments.
Effect of irrational choices on the estimation of part-worth utility functions?

Algorithms for Finding Proper Subsets

- Naive Algorithm:
  1. Perform a subset comparison operation between all pairs of configurations in an iso-price segment and build a list of all subset configurations found.
  2. For each “subset” configuration identify all attribute sets in its superset configurations.
  3. List these attribute sets with increasing cardinality. And flag all configurations which are proper subsets as irrational.

Rationale: Preference revelation and self-selection.

Transformation: Elimination of irrational configurations

Variants:

1. Filter all irrational configurations without reweighting. The number of configurations used in the WLS estimation is reduced.

   SportsLine:

	Full	Rational
Configuration types	416	325
Configurations	220 514	179 545

2. Filter all irrational configurations with reweighting of rational configurations.

Line and Engine Value (WLS, 10 vars + 943 dfs)

$$price = line + engine1 \ldots + engine9 \quad (1)$$

Variable	SportsLine	ModernLine	LuxuryLine	NoLine
Line	869.70	568.10	-109.00	-1 691.10
Signif.	*			***
Engine 1	34 424.60	34 536.50	34 667.40	35 402.30
Engine 2	38 006.90	38 295.80	38 415.20	38 714.50
Engine 3	45 935.00	46 446.90	46 524.10	46 702.20
Engine 4	44 888.60	?45 276.80?	45 337.10	?45 276.80?
Engine 5	36 324.60	36 723.30	36 773.70	37 300.70
Engine 6	39 760.80	40 051.90	40 182.90	40 530.60
Engine 7	43 294.40	43 534.30	43 669.80	44 016.30
Engine 8	54 430.00	54 841.80	54 984.40	55 158.70
Engine 9	58 872.60	59 263.70	59 386.10	59 461.50
Signif.	All ***	All ***	All ***	All ***
Adj. R^2	0.9807	98.06	0.9806	0.9808

Line and Engine Value: Weighted Residuals

	Min	1Q	Median	3Q	Max
Sports Line	-457284	-50395	-8246	35695	1260664
Modern Line	-467378	-50555	-4582	35768	1229445
Luxury Line	-464983	-51983	-5396	35754	1243001
No Line	-455711	-49405	-8225	34629	1237449

Downward skew and outliers in high price segments.

Line and Engine Value (WLS on line subsets)

Variable	SportsLine	ModernLine	LuxuryLine	NoLine
Engine 1	35 269.20	35 865.00	33 604.90	33 870.20
Engine 2	39 134.40	38 122.00	37 672.50	37 633.50
Engine 3	47 426.90	45 155.00	46 452.50	42 556.40
Engine 4	45 000.00	.	45 500.00	.
Engine 5	37 558.10	38 019.00	36 481.60	35 337.80
Engine 6	40 687.40	39 525.00	42 093.70	38 716.00
Engine 7	42 805.30	45 169.00	43 944.10	43 583.70
Engine 8	52 582.50	63 145.00	54 371.10	50 192.80
Engine 9	63 094.40	50 682.00	57 061.20	57 433.80
DF	407	153	111	238
Signif.	All ***	All ***	All ***	All ***
Adj. R^2	0.9807	97.66	0.99	0.9846

Line and Engine Value: Weighted Residuals

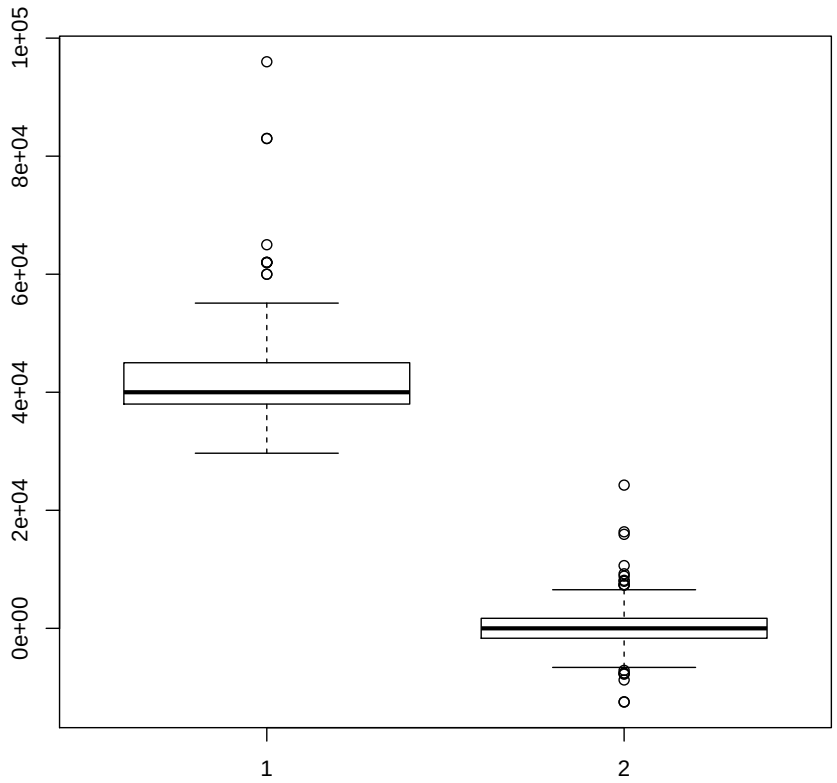
	Min	1Q	Median	3Q	Max
Sports Line	-499706	-55353	-9997	43980	1083666
Modern Line	-411506	-41444	-1784	37777	983009
Luxury Line	-308460	-44550	5063	34791	306338
No Line	-439709	-37305	-6725	27230	786927

Downward skew and outliers in high price segments.

Transformations I

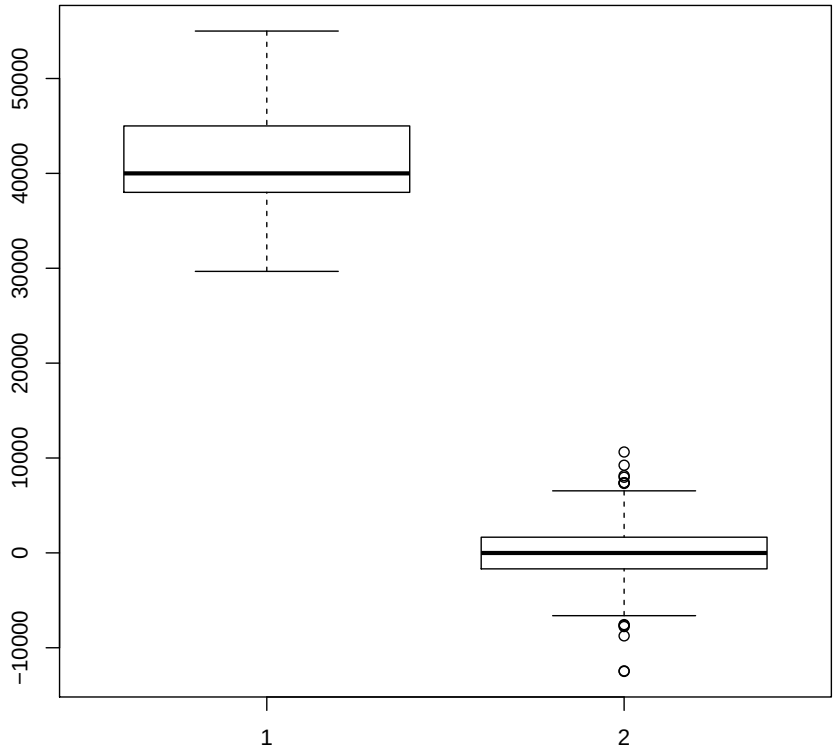
1. Elimination of irrational configurations without reweighting.
   Identify all irrational configuration types and remove them.
   (New)
2. Elimination of Price Outliers:
   From Boxplots: Before.

Transformations II



Outliers: All configurations with prices over 55000 **Euro.**

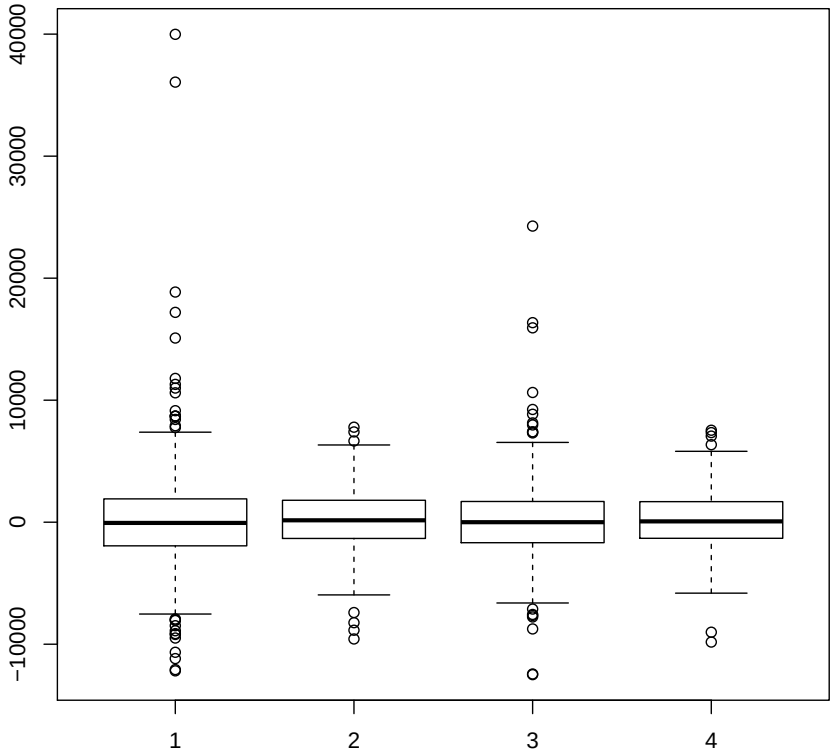
Transformations III



Effects of Transformations on Weighted Residuals for SportsLine Models I

	Min	1Q	Median	3Q	Max
Sports Line	-499706	-55353	-9997	43980	1083666
Rational SL	-396824	-34695	0	37919	517244
Rational, NOPs	-287586	-26993	1523	30758	181377

Effects of Transformations on Weighted Residuals for SportsLine Models II



Comparison of Transformed SportsLine (SL) Models I

Engines

Variable	All SL	Rat. SL	Rat. NPOs
engine1	31077	32160	33431
engine2	34599	35196	36826
engine3	38528	39377	41026
engine4	41855	43201	45002
engine5	34313	34717	36599
engine6	35138	35940	37971
engine7	37919	38923	40490
engine8	44796	45302	45740
engine9	52457	51808	48867

Comparison of Transformed SportsLine (SL) Models I

Exterior Colours

Variable	All SL	Rat. SL	Rat. NPOs
HematiteGreyMetallic	2357	2201	325
SparklingBronceMetallic	2279	1647	-100
AlpineWhite	3835	3191	635
BlackSaphireMetallic	2516	1970	45
DeepSeaBlueMetallic	1414	1105	-1043
BluewaterMetallic	6117	3640	673
PeacockBlueMetallic	3645	2732	743
GlacierSilverMetallic	4545	3904	1776
OrionSilverMetallic	660	485	-845
MineralWhiteMetallic	3300	2484	2526
Black	4212	3237	944
CrimsonRedMetallic (l.d.)	NA	NA	NA

Comparison of Transformed SportsLine (SL) Models I

RIMS

Variable	All SL	Rat. SL	Rat. NPOs
X18InchAluSportIII	-2293	-2025	-1414
X17InchAluLuxuryII	-2638	-2121	-1719
X17InchAluBasisII (l.d.)	NA	NA	NA
X18InchAluLuxuryIII (l.d.)	NA	NA	NA

19 Attributes not configured (Null Space): X18InchAluBasisII, X18InchAluLuxuryI, X17InchAluSportI, X18InchAluModernIII, X17InchAluModernII, X18InchAluBasisI, X17InchAluLuxuryI, X17InchAluBasisIII, X16InchAluBasisII, X17InchAluSportII, X18InchAluModernI, X18InchAluSportI, X16InchAluBasisI, X18InchAluLuxuryII, X17InchAluModernI, X18InchAluSportII, X18InchAluBasisIII, X16InchSteelBasis, X17InchAluBasisI, X18InchAluModernII

Comparison of Transformed SportsLine (SL) Models I

Interior Upholstery

Variable	All SL	Rat. SL	Rat. NPOs
Fabric.Leather.CombinationOyster	-982	-1386	-460
LeatherDakotaBlackwith RedContrastingSeam	-1169	-1170	20
LeatherDakotaCoralRedwith BlackContrastingSeam	-24	107	1038
FabricImolaAnthracitewith RedContrastingSeam	829	577	2096
LeatherDakotaBlackII (l.d.)	NA	NA	NA

Comparison of Transformed SportsLine (SL) Models I

Interior Upholstery

11 Attributes not configured (Null Space):

LeatherDakotaEverestGreywithBlackContrastingSeam
LeatherDakotaVenetoBeigeI
Fabric.Leather.CombinationAnthracite
LeatherDakotaVenetoBeigeII
FabricImolaAnthracitewithGreyContrastingSeam
LeatherDakotaOysterwithContrastingSeaminDarkOyster
LeatherDakotaBlackI
LeatherDakotaSaddleBrown
LeatherDakotaBlackwithContrastingSeaminDarkOyster
FabricSalomeSaddleBrown.Anthracite
FabricAnthracite

Comparison of Transformed SportsLine (SL) Models I

Trims

Variable	All SL	Rat. SL	Rat. NPOs
Aluminumwith FineLongitudinalGrain withAccentStrip inMilkyGlassLook	1228	479	-146
Fine.WoodBurrWalnut withAccentStripinChrome	1215	446	422
Aluminumwith FineLongitudinalGrain withRedAccentStrip (l.d.)	NA	NA	NA

Comparison of Transformed SportsLine (SL) Models I

Trims

8 Attributes not configured (Null Space):

Fine.WoodBurrWalnutwithBlackAccentStrip
HighPolishCashmereSilverwithAccentStripinMilkyGlassLook
AluminumwithFineLongitudinalGrainwithBlackAccentStrip
Fine.WoodFinelineAnthracitewithIntarsiaandAccentStripinChrome
AluminumwithFineLongitudinalGrainandBlackAccentStrip
HighPolishBlackwithRedAccentStrip
MattSatinSilver
Fine.WoodFinelinePorousStructuredwithAccentStripinMilkyGlassLook

Comparison of Transformed SportsLine (SL) Models I

Packages

Variable	All SL	Rat. SL	Rat. NPOs
comfort package	782	1545	1156
storage package	679	1492	348
light package interieur	3394	3297	1452

1 Attribute not configured (Null Space):

sports package

Transmission

Variable	All SL	Rat. SL	Rat. NPOs
four wheel drive	3316	1878	1450
automatic transmission	1346	1402	1060

Comparison of Transformed SportsLine (SL) Models I

Driving Assistents

Variable	All SL	Rat. SL	Rat. NPOs
cruise control with braking function	1442	139	-578
cruise control with stop go function	-184	839	-605
parking assistant	398	99	-31
rear view camera	-525	-1145	-1858
lane change warning	-2356	-3119	-1553
lane departure warning	2422	1326	2895
road sign recognition	-329	857	674
head up display	-6456	-4151	-2432

Comparison of Transformed SportsLine (SL) Models I

Steering, light, chassis, ...

Variable	All SL	Rat. SL	Rat. NPOs
adaptive chassis with lowering	1554	91	1669
variable sports steering	-4742	-4525	-2255
xenon light	901	748	365
adaptive cornering light	-672	213	1588
glass sunroof	1105	1832	1471
sun protection blind	8343	7206	35
performance leather steering wheel	1409	1495	1109

1 Attribute not configured (Null Space):

sport leather steering wheel

Comparison of Transformed SportsLine (SL) Models I

Convenience, Security, ...

Variable	All SL	Rat. SL	Rat. NPOs
seat heating for front seats	-520	97	-247
electric seat adjustment	186	-466	-777
lumbar support for front seats	-622	-1302	-1158
climate control	1348	827	589
alarm system	283	394	-271
arm rest for front seats	-109	-394	222
comfort access	-466	-608	57
hitch	713	1817	2412

1 Attribute not configured (Null Space):

sports seats for front seats

Comparison of Transformed SportsLine (SL) Models I

Navigation/Media/Communication

Variable	All SL	Rat. SL	Rat. NPOs
navigation system business	770	775	1058
hifi system	-415	46	-122
dvd changer	2653	3346	2224
mobile phone prep with bluetooth usb	-1071	-1312	84
digital radio	2084	2272	14

Analyis of Singularities for Rat. NPOs SL Model I

- Null space:
  41 attributes
- Structure of linear dependencies:
  At most a 5 dimensions.
  TODO: Find exact structure!
  Could explain some of the negative values by an equivalent model with the same fit.

Conclusion

- Internet car configurations contain many irrational choices and the pricing of configurations seems to be inconsistent.
- Recommendations for evidence-based hard sell tactics can be inferred from such data sets.
- A field experiment would be nice ...

References I


Haug, A. (2007).
Representation of Industrial Knowledge – as a Basis for Developing and Maintaining Product Configurators.
PhD thesis, Department of Manufacturing Engineering & Management, Technical University of Denmark, Lyngby.


Morgenstern, O. and Neumann, J. v. (1990).
Theory of Games and Economic Behavior.
Princeton Univ Press, Princeton.


Pine, B. J. (1999).
Mass Customization: The New Frontier in Business Competition.
Harvard Business School Press, Harvard.