Statistics Finland

The Making of Hedonic Index Numbers

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1. Background

- Previously, the price index for second-hand cars was calculated by Autovista Group for the purpose of CPI
- From the beginning of 2023, Statistics Finland has done the calculation itself

- The same second-hand car is not sold every month, so it is impossible to follow the price of the same car over time

- In this study, we combine hedonic quality adjusting and traditional index calculation
- In Finland, the same method is used for the prices of houses as well as for the rents of offices and shops

2. Data and data pre-processing

- Data is received on a daily basis from one major selling portal for second-hand cars in Finland
- Only the latest sales announcement of the month is considered
- The sales announcement data is supplemented with additional characteristics information from the vehicle register data from Finnish Transport and Communications Agency
- The monthly data contains approximately 75 000 individual sales announcements of second-hand cars
- For index calculation purposes, only the following are taken into account:
    - Second-hand cars with ”sold”-status purchased from car dealers
    - Passenger cars
    - Cars aged between one and twenty years
    - Cars with price greater than 2000 euros
    - Mileage needs to be less than one million kilometers

3. Steps of the process for producing the hedonic price index

1. **Definition and estimation of price model** incl. statistical tests
2. **Aggregation and Oaxaca-decomposition**
3. **Index calculation**

3.1 Definition and estimation of price model 1/5

- The price model is semilogarithmic:

$$log(p_{it}) = \alpha_{01t} + \cdots + \alpha_{0k_1t} + x'_{it}\beta_t + \varepsilon_{it},$$

where p is the unit price of a second-hand car, parameters α represent stratum effects and term ε is random error term

- The unknown parameters β and α are estimated using the ordinary least squares method (OLS)

The explanatory variables used in the price model

Variable	Description
x_1	Gearbox type: If automatic $x_1 = 1$, else $x_1 = 0$.
x_2	Towing hook: If towing hook $x_2 = 1$, else $x_2 = 0$.
x_3	Service history: If service history is available $x_3 = 1$, else $x_3 = 0$.
x_4	Cruise control: If cruise control $x_4 = 1$, else $x_4 = 0$.
x_5	Selling time of a car, months.
$x_6 = sqrt(x_5)$	Square root of the selling time of a car.
x_7	Age of a car, years.
$x_8 = sqrt(x_7)$	Square root of the age of a car.
x_9	Mileage (ten thousand).
$x_{10} = sqrt(x_9)$	Square root of mileage.
x_{11}	Power/Weight ratio of a car.
$x_{12} = sqrt(x_{11})$	Square root of Power/Weight of a car.

3.1 Definition and estimation of price model 2/5

- We define several hierarchical partitions of second-hand cars (homogenous stratums)
- Using the F-test, we select the suitable partition: model 6

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
	No categori-zation	Size of a car	Size of a car × Make	Size of a car × Make × Model	Size of a car × Make × Model × Driving Power	Size of a car × Make × Model × Driving Power × Type of a car
		Model 1 vs 2	**Model 2 vs 3**	**Model 3 vs 4**	**Model 5 vs 4**	**Model 6 vs 5**
Test statistic		11896	1872	711	36.8	10.7

3.1 Definition and estimation of price model 3/5

- We define several classifications of price models
- Using the F-test, we select the suitable classification of price model: model 8

	Model 6	**Model 7**	**Model 8**
	No heterogeneity	Size of a car	Size of a car × Make
		Model 7 vs 6	**Model 8 vs 7**
Test statistic		206.5	45

3.1 Definition and estimation of price model 4/5

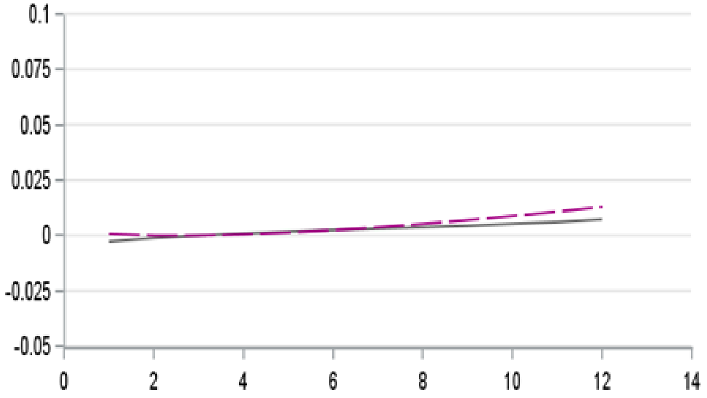
Year	2020	2021
Number of observations	287936	269663
Number of equations	72	74
Number of stratums/categories	1594	1691
Degrees of freedom	285478	267084
SSE	5401.6405077	4908.43633
R2	0.9645034599	0.9675392005
RMSE	0.1375550427	0.1355650208

	2020	2021
Constant	9.9126394001	9.8211262087
If automatic gearbox $x_1 = 1$, else $x_1 = 0$	0.0902673948	0.0923941505
If towing hook $x_2 = 1$, else $x_2 = 0$	0.0118209506	0.0113174535
If service history is available $x_3 = 1$, else $x_3 = 0$	-0.010492392	-0.008856039
If cruise control $x_4 = 1$, else $x_4 = 0$	0.017682513	0.0190084745
Selling time of a car, x_5	-0.000386744	0.0036841099
$x_6 = x_5^{1/2}$	0.0054383443	-0.012634214
Age of a car, x_7	-0.138809764	-0.135251635
$x_8 = x_7^{1/2}$	0.2915511757	0.2950576677
Mileage, x_9	-0.033047764	-0.033221364
$x_{10} = x_9^{1/2}$	0.0180405738	0.026330353
Power/Weight ratio of a car, x_{11}	12.089654612	9.8976375615
$x_{12} = x_{11}^{1/2}$	-2.549090343	-1.520907481

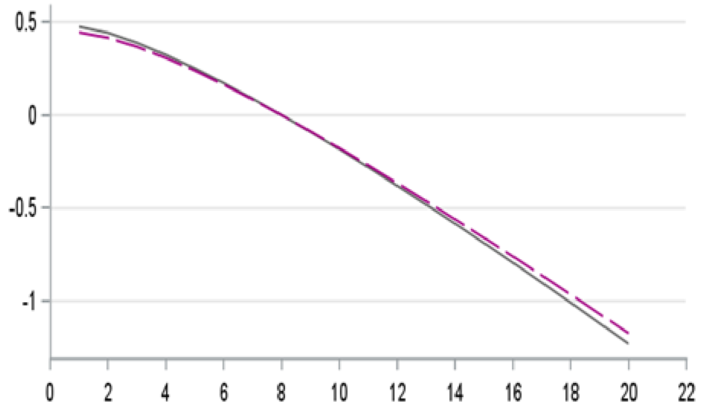
- The price model is estimated for each year
- Estimation results for model 8
  - Selling time of a car has little effect on price
  - Age of a car and mileage have a negative effect on price
  - Power/Weight ratio of a car has a positive effect on price

3.1 Definition and estimation of price model 5/5

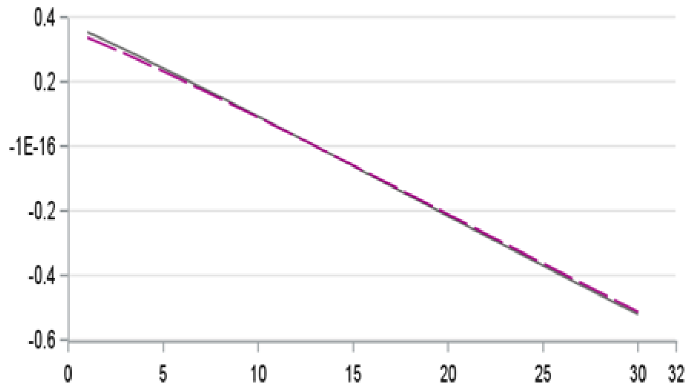
The price effect of selling time (months) on the average log-prices in year 2020 and 2021 (red line)



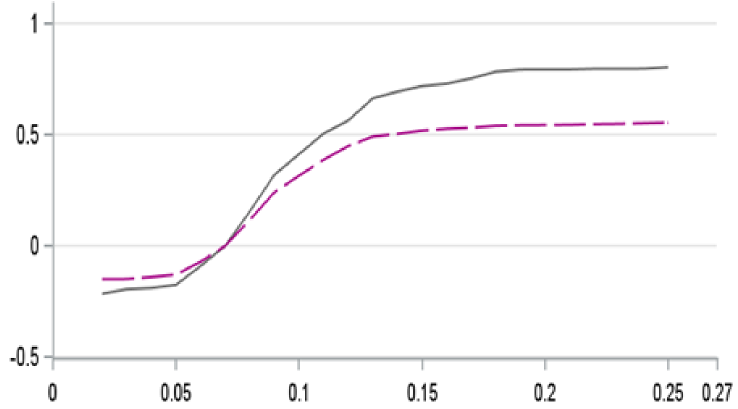
The price effect of age (years) on the average log-prices in year 2020 and 2021 (red line)



The price effect of mileage (ten thousand) on the average log-prices in year 2020 and 2021 (red line)



The price effect of power/weight ratio (kW/kg) on the average log-prices in year 2020 and 2021 (red line)



3.2 Aggregation and Oaxaca-decomposition

- We aggregate price models from observations into stratums of the partition
- We test unweighted geometric and arithmetic averages in aggregation
- The quality adjusting is performed using decomposition introduced by Oaxaca (1973)
  - The decomposition splits the actual average price change into quality corrections and quality adjusted price changes for any stratum

(1) Price-ratio = {Quality corrections } + {Quality adjusted price change conditional on $\bar{\boldsymbol{x}}'_{kt}$}

A = QC + QA

- The equation (1) can be represented as

$$log(\bar{p}_{kt}/\bar{p}_{k0}) \quad = \quad log(\tilde{p}_{kt}/\bar{p}_{k0}) \quad + \quad log(\bar{p}_{kt}/\tilde{p}_{kt}),$$

where $log(\bar{p}_{kt})$ is the average price for the current month, $log(\bar{p}_{k0})$ is the average price for the base period and

$log(\tilde{p}_{kt}) = \hat{\alpha}_{k0} + \bar{\boldsymbol{x}}'_{kt}\widehat{\boldsymbol{\beta}}_{j0}$ is the current month's estimated price using the base period valuation of characteristics $\widehat{\boldsymbol{\beta}}_{j0}$

- The price model estimates used are always from the base period

3.3 Index calculation

- The averaged stratum-level price decompositions are summed up to COICOP7-level using weights $w_{k,f}$ of index number formula f

  $exp\{\sum_k w_{k,f}\, log(\bar{p}_{kt}/\bar{p}_{k0})\} = P_{f,A}^{t/0}$ is the price index for actual average prices (A)

  $exp\{\sum_k w_{k,f}\, log(\tilde{p}_{kt}/\bar{p}_{k0})\} = P_{f,QC}^{t/0}$ is the price index for quality corrections (QC)

  $exp\{\sum_k w_{k,f}\, log(\bar{p}_{kt}/\tilde{p}_{kt})\} = P_{f,QA}^{t/0}$ is price index for quality adjusted price changes (QA)

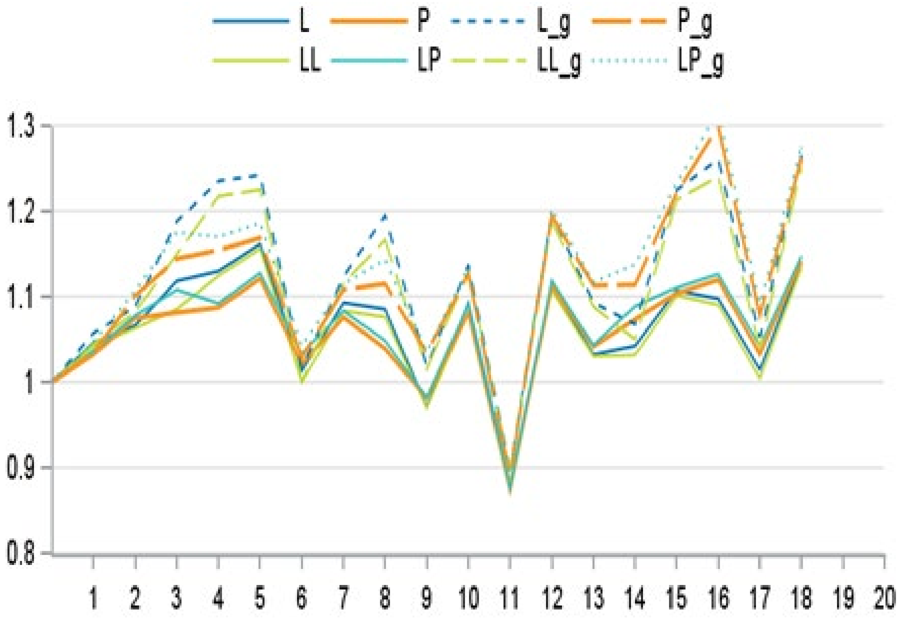
  that satisfy the following equation

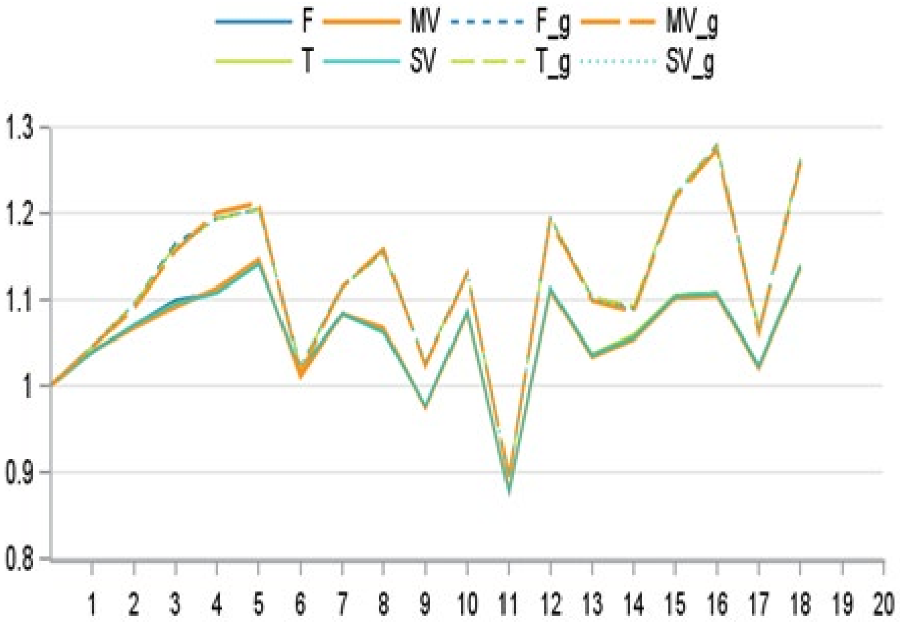
$$P_{f,A}^{t/0} = P_{f,QC}^{t/0} \cdot P_{f,QA}^{t/0}$$

- In our case the base period is a previous year normalized as an average month
  - We use the flexible basket approach
- We test different index number formulas

4. Results 1/3

- Index series for actual average prices for ‘Small cars’ make ‘Honda’. Indices based on geometric are dotted lines and arithmetic are solid lines

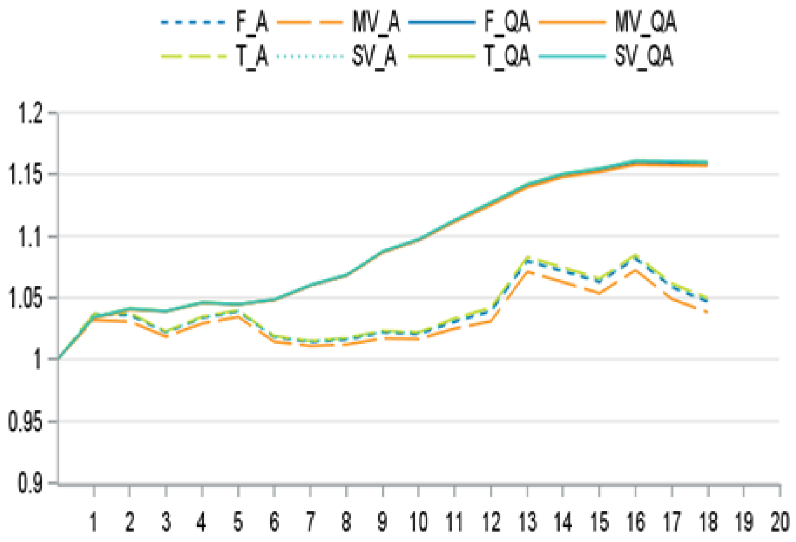


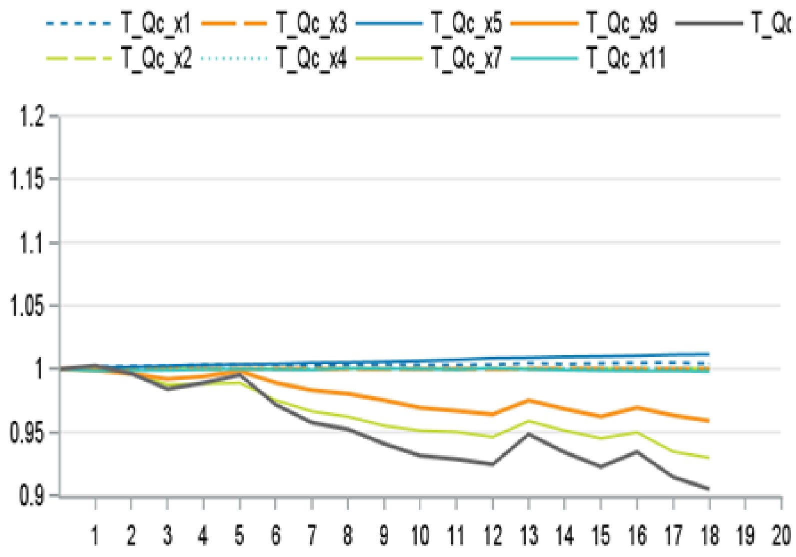


- Basic formulas are contingently biased, deviating from each other
- Price ratios using unweighted arithmetic or geometric average prices are closely related

4. Results 2/3

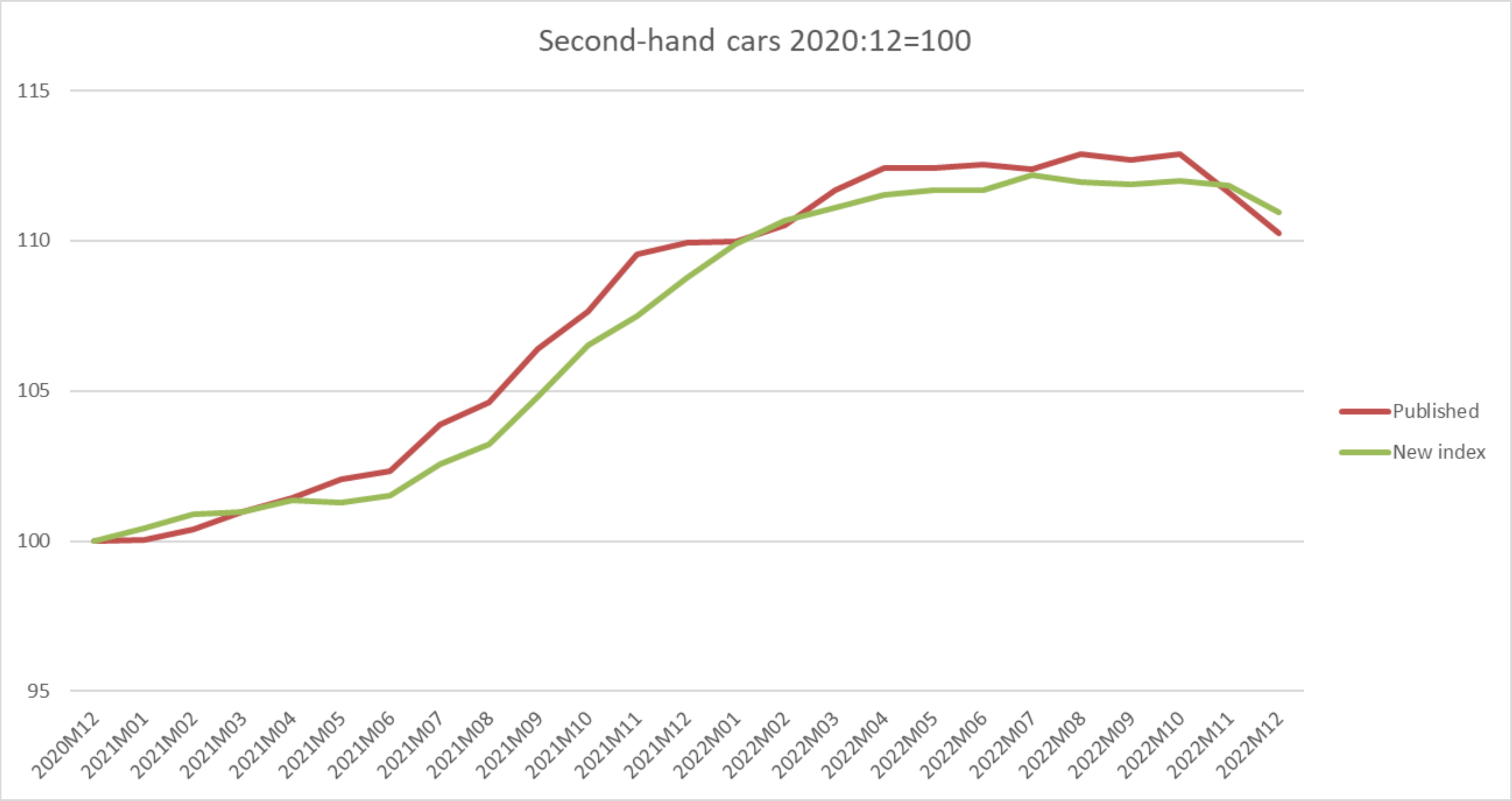
- Hedonic index series for actual arithmetic average prices (A), quality adjusted prices (QA) and quality corrections (Qc_x)





- Age of a car (x7) and mileage (x9) have a negative effect on actual average prices
    - Sold cars are older and more driven in the current period
- Index series for actual prices must be corrected upwards, which is index series for quality adjusted prices

4. Results 3/3



- The differences between the series are due to the data source, regression model variables, index formula and strategy

Things to consider when designing a hedonic application (HICP Manual)

- How many and which quality-related variables to include in the regression equation: Our model has 12 variables (slide 6)
- Whether to use another (finer or coarser) stratification when estimating the regression coefficients than when computing the index: We use a coarser stratification for estimation (slide 8)
- How frequently to re-estimate the regression coefficients: We re-estimate every year
- Whether to weight the prices when estimating the regression coefficients: We use equal weights
- Which function form to use; semi-logarithmic, double-logarithmic or other: Our model is semi-logarithmic (slide 6)
- Whether valid or spurious results are obtained: Statistical inference leads to selection of the best price models. Estimators of the price models are the best linear unbiased estimates (BLUE)
- Whether the method improves the accuracy of the index so much that it outweighs the often relatively high cost for design work and for collection of quality-related data: Yes, see slide 14

5. Conclusions

- Our proposal for producing a hedonic price index is as follows:
    1. Use suitable partition in estimation of price models
    2. Aggregate price models into stratum-level by using arithmetic average
        - Arithmetic average is more interpretable than geometric average
    3. Form price decompositions for stratums (Oaxaca)
    4. Aggregate stratum-level price decompositions into COICOP-level using Törnqvist formula and base strategy with a flexible basket, that is free of chain drift

- This method is widely used in Statistics Finland

Statistics Finland

Thank You!

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