Dynamic simulation of the German vehicle market

Lars Kröger, Benjamin Kickhöfer, Francisco J. Bahamonde-Birke, Falko Nordenholz, Marie-Sophie Bolz

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Motivation

• Necessity of a **Car Ownership Model** (for Passenger Cars):
  • **Impact on mode-choice**-analysis (short-term)
  • Size and Composition of the **future Car fleet** (long-term)
  • Relevant for Transport system analysis (e.g. calculation of emissions)
  • Tool for **Policy Analysis** and Evaluation (Sensitivity for policy adjustments, e.g. fiscal)

• Further goal:
  • Basis for implementing decision behaviour on (usage of) other mobility tools (e.g. new autonomous mobility concepts) and interaction with the “Classical Car-Ownership-Model” → “**Mobility-Tool-Ownership-Model**”
CAST: **CAr STock model**

**Disaggregated Dynamic Model**
Further development of ideas from Mohammadian and Miller (2003)

Based on **annually household decisions on car purchases**
Car fleet composition results mainly from decisions of purchases, holding time distributions, and in parts from a scrapping-function of vehicles

Empirical data from MiD 2008: **Cross-Sectional-Household RP data** (with a vehicle data file including information on vehicle purchases but not on losses or sells of vehicles) → ~25k Households, ~35k Vehicles
Additional data from KBA and DAT for calibration of the resulting car fleet
General Overview: Household Perspective / Submodels

HouseholdSelector *(Mixed Logit)*

- **New**:
  - No Buy
  - Commercial New
  - Private New
  - Private Used

- **Used**:

VehicleTechnologySelector *(Mixed Logit)*

- **Small**:
  - Small Gasoline
  - Small Diesel
  - Medium Gasoline
  - Medium Diesel
  - Large Gasoline
  - Large Diesel

UsedVehicleMarketClassSelector *(Ordered Logit)*

- Good
- Average
- Bad

- only for „Private Used“
General Overview:
„Life Cycle“ of the Vehicles

New Vehicle Market *(demand-driven)* → Assigned Vehicles → Used Vehicle Market *(supply-driven)*

- Household-based probabilities
- HoldingTimeDistribution *(VehicleMarket)*
- [Household-based probabilities]
- Used Vehicle Market Class *(vehAge, odometer)*
- scrappingFunction*(vehAge)*

Unassigned Vehicles

Exiting States:
- Scrapped Vehicles

Demand-driven vs. supply-driven market.
Overview of Submodels

- Holding time distributions
- Classification of the Used Vehicle Market Class
- Scrapping of Vehicles
- „Shadow Pricing“
Holding time distributions

- Holding time distributions of the different Vehicle Markets (Private Used, Private New, Commercial New) derived from exponential density functions

- **Average Holding Time** of Private Used Vehicles shorter than that of Private New Vehicles

- **Shortest average Holding Time** for „Commercial New“ Vehicles

- „Vehicle Age at the time of purchase“ (of used cars) as influencing variable only tested so far (the older the vehicle, the shorter the average holding time)

- **Calculation of total fleet size** (for comparison to the control variable) is possible as sum of the products of number of purchases and average holding time of all vehicle markets (assumption of unchanged conditions):

\[
FS_t = \sum_i X_i \times \bar{h}_i
\]

- \(FS_t\) ... Total Fleet Size based on the purchases in year \(t\) (if conditions remain unchanged)
- \(X_i\) ... Number of Vehicle Purchases on the Vehicle Markets \(i\) (CN, PN, PU) in year \(t\)
- \(\bar{h}_i\) ... Average holding time of the vehicles from vehicle market \(i\), purchased in year \(t\)
Holding time distributions

\[ t_H = ? \]

\[ t_{OW} \]

\[ t_P \]

\[ t_O \]

\[ t_S = ? \]

Relative frequency

- Exponential Density Function

\[ f_H = -\frac{\partial P(t_{Alt})}{\partial t_{Alt}} \cdot t_{Alt} \]

Own calculations based on MiD 2008, DAT (2017)

Choice 1: Private-Used: \( \lambda = 0.29 \), \( E(hd) = 6.37 \)

Choice 2: Commercial-New: \( \lambda = 0.45 \), \( E(hd) = 3.92 \)

Choice 3: Private-New: \( \lambda = 0.18 \), \( E(hd) = 10.92 \)

Own calculations based on DAT (2017)
Classification of the Used Vehicle Market Class

\[ f(x) = \beta_{odo} \cdot \frac{odo}{14000}^2 + \beta_{age} \cdot age^2 \]

Assumption:
Influence of mileage is 50% higher than the influence of the vehicle age:
\[
\beta_{age} = 2 \\
\beta_{odo} = 3
\]

Dependent Variable
UsedVehicleMarket Class („Good“, „Average“, „Bad“) is based on \( f(x) \)

Classification based on MiD 2008 data (all purchases of used vehicles):
Scraping of Vehicles

• **Scraping** is the **final destruction** of vehicles but here also the **export of used vehicles** to other vehicle markets (➔ „Vehicles are leaving the assigned and unassigned vehicle fleet“)

• **Scraping function depends on vehicle age** (could also depend on actual odometer value cf. the classification of Used-Vehicle-Markets) ➔ Use of a Weibull-Function, cf. e.g. Kolli 2010

• Probability of scrapping a vehicle has an **influence** on the size of the unassigned vehicle fleet after the model step of purchasing used vehicles and thus also on **average vehicle age in the vehicle fleet**
Market mechanism in case of scarcities
→ „Shadow Pricing“

• Used-Vehicle Market is supply-driven → scarcities possible

• 1. Consideration within single markets (integrated in the scenarios)
• 2. Integration in the whole model system (integrated only in the new parameter estimations so far, see Presentation of Bahamonde-Birke et al. at this Conference) → necessary for simulating feedback effects between the number of buyers of new and used vehicles and the avoidance/postponing of buying a vehicle

→ Highly relevant for emerging technologies (e.g. the Used-Vehicle Market for Electric Vehicles)
→ A combination of an exogeneous technology diffusion model and shadow pricing is possible also for the New-Vehicle Market
Market mechanism in case of scarcities → „Shadow Pricing“

- Calculation of the Utility of the alternatives in the Vehicle Technology Selector Submodel:

\[ U_{t.m.i} = \beta_{asc.t.m} + \sum_{p} \beta_{p.t.m} \cdot X_{p.t.m.i} + \sum_{q} \sigma_{q.t.m} \cdot Y_{p.t.m.i} + \varepsilon_{t.m.i} \]

With:
- \( U_{t.m.i} \) ... Utility of the vehicle-technology- and vehicle-market-specific alternative \( t.m \) of an individuum \( i \)
- \( \beta_{asc.t.m} \) ... Alternative-specific constant for \( t.m \)
- \( \beta_{p.t.m} \) ... Parameter values for parameter \( p \) for \( t.m \)
- \( X_{p.t.m.i} \) ... Variables for \( t.m \) for \( i \)
- \( \sigma_{q.t.m} \) ... Parameter values for parameter \( q \) for \( t.m \)
- \( Y_{p.t.m.i} \) ... Normal distributed value for \( t.m \) for \( i \)
- \( \varepsilon_{t.m.i} \) ... Error term for \( t.m \) for \( i \)

- **Calculation** of the **Utility** of the alternatives in the Vehicle Technology Selector **with consideration** of the vehicle-technology- and vehicle-market-specific \( (t.m) \) shadow price \( p_{s.t.m} \):

\[ U_{t.m.i} = \beta_{asc.t.m} + \sum_{p} \beta_{p.t.m} \cdot X_{p.t.m.i} + \beta_{price.t.m} \cdot p_{s.t.m} + \sum_{q} \sigma_{q.t.m} \cdot Y_{p.t.m.i} + \varepsilon_{t.m.i} \]

- Difficulty of getting the exact shadow prices
  - **Heterogeneity of user preferences** require an iterative process of shadow price setting
  - Stepwise (discretised) process could be more realistic with the restriction of having not necessarily a final **complete market clearance**
Calibration of CAST and control variables

- **Model simulation** of CAST with use of the estimated parameters for purchases leads **not necessarily** to the **right fleet size and composition**
  - Estimated **parameters** for buying vehicles **vary over the years** (e.g. because of medium-term business cycles, market introduction of certain vehicle models)
  - Estimated **parameters** for buying vehicles can follow a **trend over time due to a change of behaviour** (e.g. cohort effects due to higher rates of driver license holding)
- Composition and total size of the population can change over time due to **socioeconomic and sociodemographic changes**

- (New technologies and mobility concepts can massively change the parameter estimations and require new information e.g. on correlations)
Calibration of CAST and control variables

- Necessity of external data sources for calibration
  - MiD data has weaknesses concerning the total number of vehicles → Iterative proportional fitting of the MiD data for reweighting in advance of the parameter estimation
- Use of control variables (data from KBA and DAT):
  - Total fleet size, Average vehicle age, Composition of the fleet (Size and Drivetrains)
  - Total number of new vehicles p.a., Total number of bought used vehicles p.a.
  - distribution within households (shares of households with zero/one/two/three/... vehicles)

- Integration of a fourth quasi-static Vehicle Market ("Company Cars", e.g. rental cars, vehicles of craftsmen) → size and composition remains constant over time, vehicles get on the used vehicle market after finishing the holding time
Excursus

Scenarios from DLR-VF-Project VEU II (cf. Kugler et al. 2017)

Car Fleet (Size*Drivetrain, CAST-Base-Case-Scenario)

Shell (2014)

→ Integration of socioeconomic/-demographic effects is necessary for comparability
Excursus

Relative stable situation of market shares 18th of September 2015: Start of „Emissions Scandal“

Market share of different drivetrain technologies within new vehicle registrations in Germany (Data: KBA (2012-2018))

• **Short run:** Large influence of exogeneous factors (e.g. „The Emissions Scandal“), with an impact on behaviour which could not be modeled here (impact on total fleet will be largely visible within some years)

• **Long run:** Policy analysis
Integration of New Technologies

• Based on the idea of Jensen et al. (2017) an increase of the parameter values for Evs over time is implemented to match the target value of the German Government of 6 Mio. EVs in 2030 (cf. BMWi/BMVBS/BMU/BMBF 2011)
  • For simplification only BEVs in the simulation (no Mild-/Full-HEV or PHEVs)
  • Orientation of the parameters on Gasoline and Diesel parameters (problem of missing knowledge on correlations)
  • Additional input to forecast prices on BEV technology based on predicted price levels per battery capacity unit (cf. Berckmans et al. 2017, Curry 2017)
• Choice option for BEVs as additional drivetrain alternative

• Necessity of empirical data from questionnaires for EV and AV adoption for further development of the Fleet Model (only conceptual integration with hypothetic parameters/variables so far)
• Additional uncertainties e.g. on the depreciation of EV-technology-prices in comparison to the depreciation level of conventional vehicles
### Scenario Description

- **Modeling of CAST with JAVA**
- **1 % Sample (~400k Households, ~450k Vehicles), 10 Repetitions**
- **Scenario Years 2010-2050**

### Scenarios 0-3: Only conventional Drivetrains

<table>
<thead>
<tr>
<th>Scenario</th>
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<tr>
<td>Scenario 0</td>
<td>Base-Case-Scenario</td>
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<tr>
<td>Scenario 1</td>
<td>Fuel Price Increase: +20% (Diesel &amp; Gasoline) from 2020 onwards</td>
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<tr>
<td>Scenario 2</td>
<td>Diesel-Fuel-Tax-Increase: +50% from 2020 onwards</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Diesel-Vehicle-Tax for year of construction &lt;2015: +100%</td>
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### Scenarios 10-12: Introduction of BEVs as example for emerging technologies

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<td>Scenario 10: Base-Case-Scenario* (with BEVs)</td>
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<td>Scenario 11: Fuel Price Increase: +20% (Diesel &amp; Gasoline) from 2020 onwards</td>
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<td>Scenario 12: No registrations for new conventional Vehicles (Diesel &amp; Gasoline) from 2030 onwards</td>
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CAST: Scenarios

Scenarios 0-3:
Only conventional Drivetrains

- Scenario 0: Base-Case-Scenario
- Scenario 1: Fuel Price Increase: +20% (Diesel & Gasoline) from 2020 onwards
- Scenario 2: Diesel-Fuel-Tax-Increase: +50% from 2020 onwards
- Scenario 3: Diesel-Vehicle-Tax for year of construction <2015: +100%

→ Scenario 1 emphasizes the necessity of the integration of the HouseholdSelector and the VehicleTechnologySelector (otherwise no effect on total Vehicle Fleet Size)
→ Effects in Scenario 1 and 3 rather low (However, the feasibility of the policy in Scenario 2 is uncertain because of the effects on other economic sectors)
CAST: Scenarios

**Scenarios 10-12: Introduction of BEVs as example for emerging technologies**

- **Scenario 10:** Base-Case-Scenario* (with BEVs)
- **Scenario 11:** Fuel Price Increase: +20% (Diesel & Gasoline) from 2020 onwards
- **Scenario 12:** No registrations for new conventional Vehicles (Diesel & Gasoline) from 2030 onwards

![Graph showing relative change compared to Scenario 10 for BEV, Diesel, and Gasoline across years 2010 to 2050]

→ Fuel Price Increase leads to a slight increase of the BEV fleet size
→ Reduction of Gasoline Vehicles is larger than the reduction of Diesel Vehicles
CAST: Scenarios

Scenarios 10-12: Introduction of BEVs as example for emerging technologies

- Scenario 10: Base-Case-Scenario* (with BEVs)
- Scenario 11: Fuel Price Increase: +20% (Diesel & Gasoline) from 2020 onwards
- Scenario 12: No registrations for new conventional Vehicles (Diesel & Gasoline) from 2030 onwards

→ BEV-share in total Vehicle Fleet in Scenario 12 in 2050 at 88% compared to 25% in Scenario 10 (no adaption e.g. of the holding time distributions)
Conclusion & Outlook

• CAST developed as a **dynamic disaggregate car fleet model with annually household decisions on car purchases** based on cross-sectional RP data from MiD 2008

• Several other data sources (e.g. KBA and DAT) for model and fleet size calibration (assumptions and functions integrated for holding time distributions and vehicle scrapping)

• **Scenario simulations** show the applicability of the model to analyze the impact of policies (e.g. fiscal) on car fleet development

• **Model Structure** is transferable to other National Car Markets

• **Sociodemographic forecasts have to be integrated** to give information on absolute Vehicles Sizes in the scenarios

• **Empirical data for emerging technologies** (i.e. electric vehicles and automated vehicles) has to be integrated

• **Model development in direction of a „Mobility-Tool-Ownership-Model“** and to an interaction with travel demand models
References

- DAT (several, annually reports): DAT Report. Deutsche Automobil Treuhand GmbH.
- DLR (unpublished): Projekt „Verkehrsentwicklung und Umwelt II“. Deutsches Zentrum für Luft- und Raumfahrt e. V.