Dynamic simulation of the German vehicle market

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7th Symposium of the European Association for Research in Transportation – hEART 2018
5th–7th September 2018
Athens / Greece

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**"

General Overview: Classification and Data of CAST

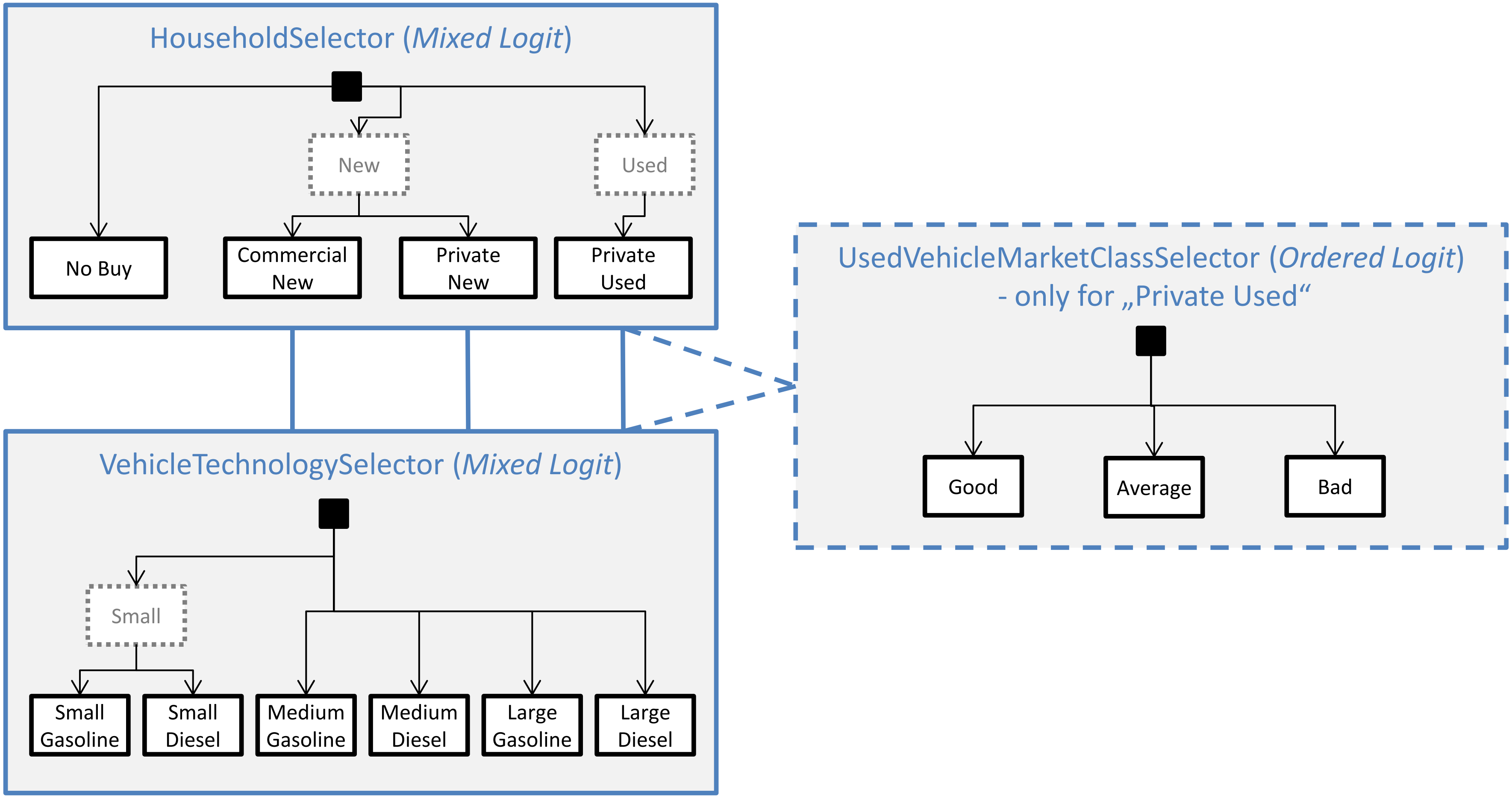
- **CAST: CAr STock model**

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

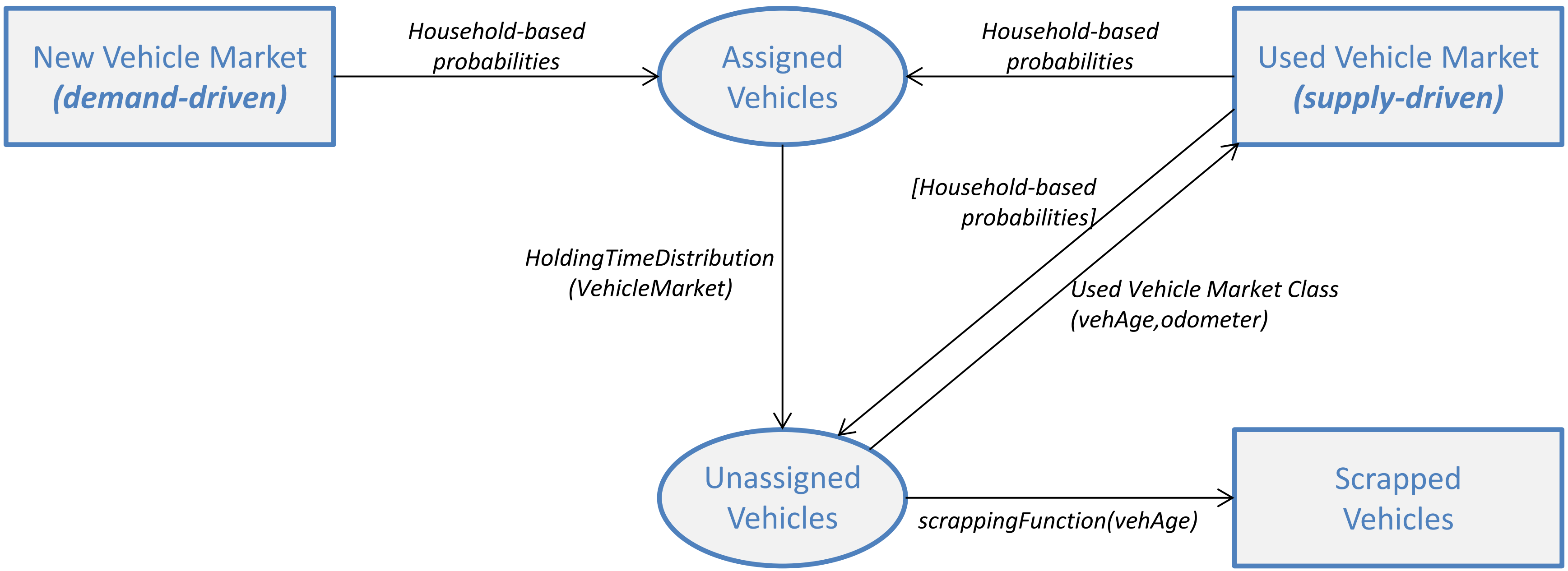
- Based on **annually household decisions on car purchases**
- Car fleet composition results mainly from decisions of purchases, holding time distributions, and in parts from a scrapping-function of vehicles

- 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



General Overview:
„Life Cycle“ of the Vehicles



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):

$$FS_t = \sum_i X_i * \bar{h}_i$$

FS_t ...*Total Fleet Size based on the purchases in year t (if conditions remain unchanges)*
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*

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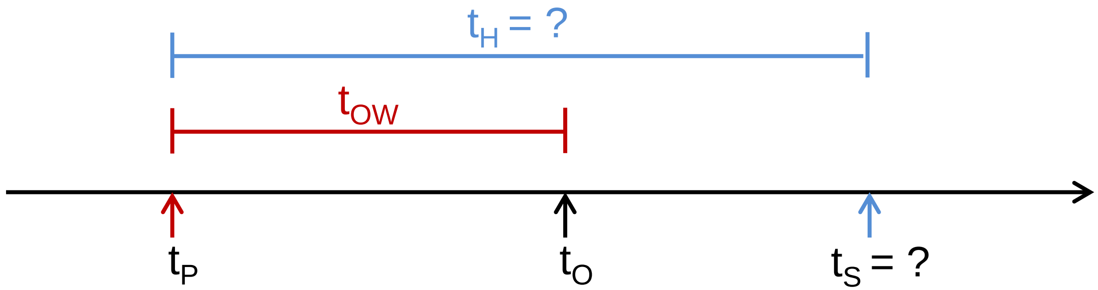
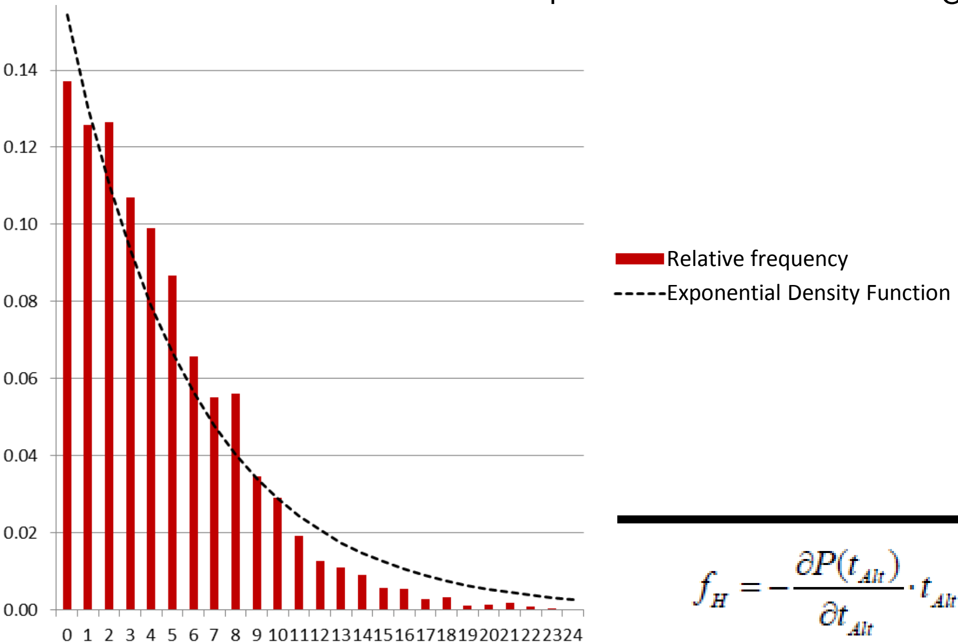
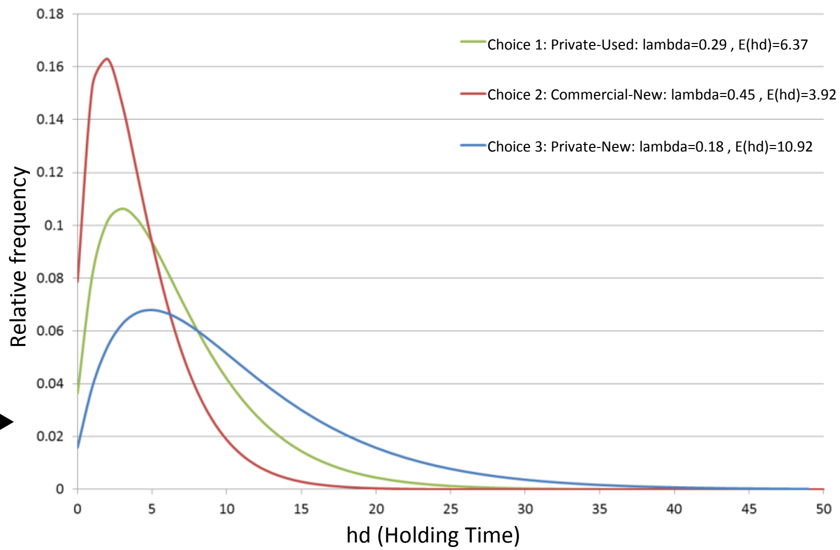
Holding time distributions





Own calculations based on MiD 2008, DAT (2017)

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



Own calculations based on DAT (2017)

Classification of the Used Vehicle Market Class

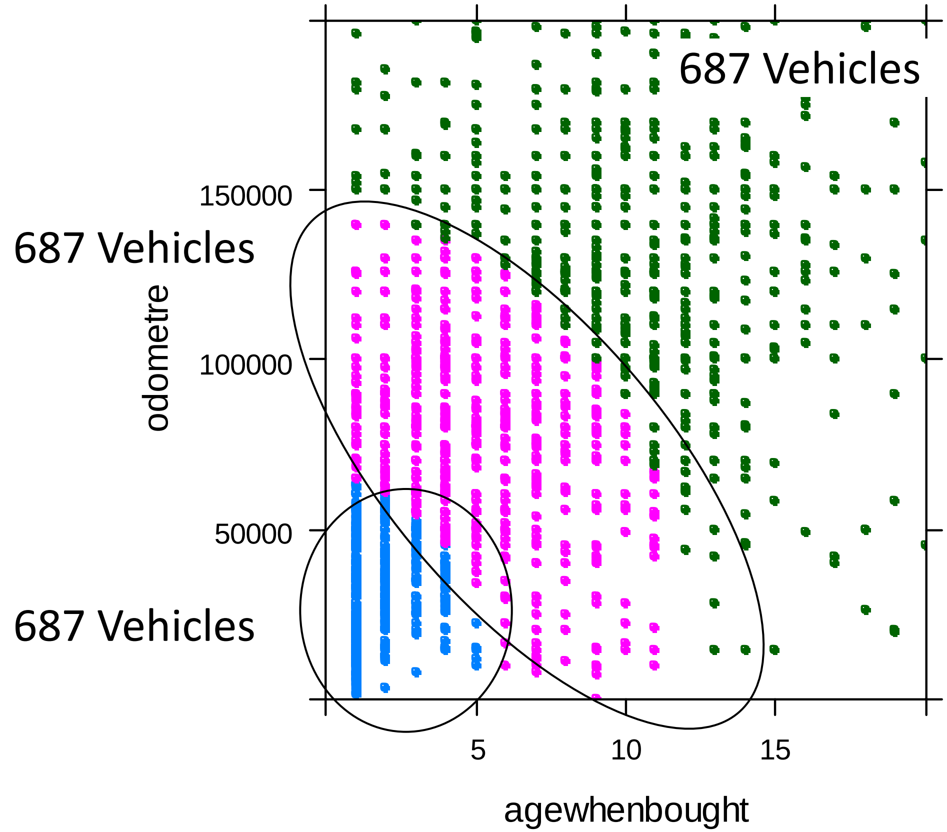
$$f(x) = \beta_{odo} * \frac{odo}{14000}^{2} + \beta_{age} * age^{2}$$

Assumption:
Influence of **mileage**
is 50% higher than the **influence**
of the **vehicle age**:

$$\beta_{age} = 2$$
$$\beta_{odo} = 3$$

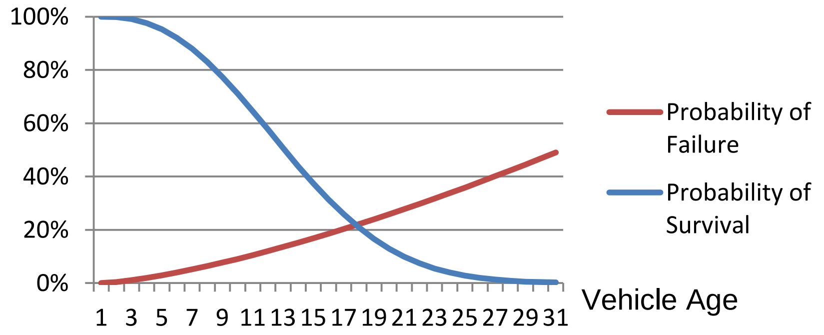
Dependent Variable
UsedVehicleMarket Class
(„Good“, „Average“, „Bad“)
is based on $f(x)$

Clasification based on MiD 2008 data
(all purchases of used vehicles):



Scrapping of Vehicles

- **Scrapping** 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“)
- **Scrapping 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**



Own representation

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 technolgies** (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

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Market mechanism in case of scarcities → „Shadow Pricing"

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

$$U_{t.m.i} = \beta_{asc.t.m} + \sum_{p} \beta_{p.t.m} * X_{p.t.m.i} + \sum_{q} \sigma_{q.t.m} * Y_{p.t.m.i} + \varepsilon_{t.m.i}$$

With:

$U_{t.m.i}$	… Utility of the vehicle-technology- and vehicle-market-specific alternative $t.m$ of an individuum i	$X_{p.t.m.i}$	… Variables for $t.m$ for i
		$\sigma_{q.t.m}$	… Parameter values for parameter q for $t.m$
$\beta_{asc.t.m}$	… Alternative-specific constant for $t.m$	$Y_{p.t.m.i}$	… Normal distributed value for $t.m$ for i
$\beta_{p.t.m}$	… Paramete values for parameter p for $t.m$	$\varepsilon_{t.m.i}$	… 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 $p_{s.t.m}$**:

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

- 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 cylces, 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)

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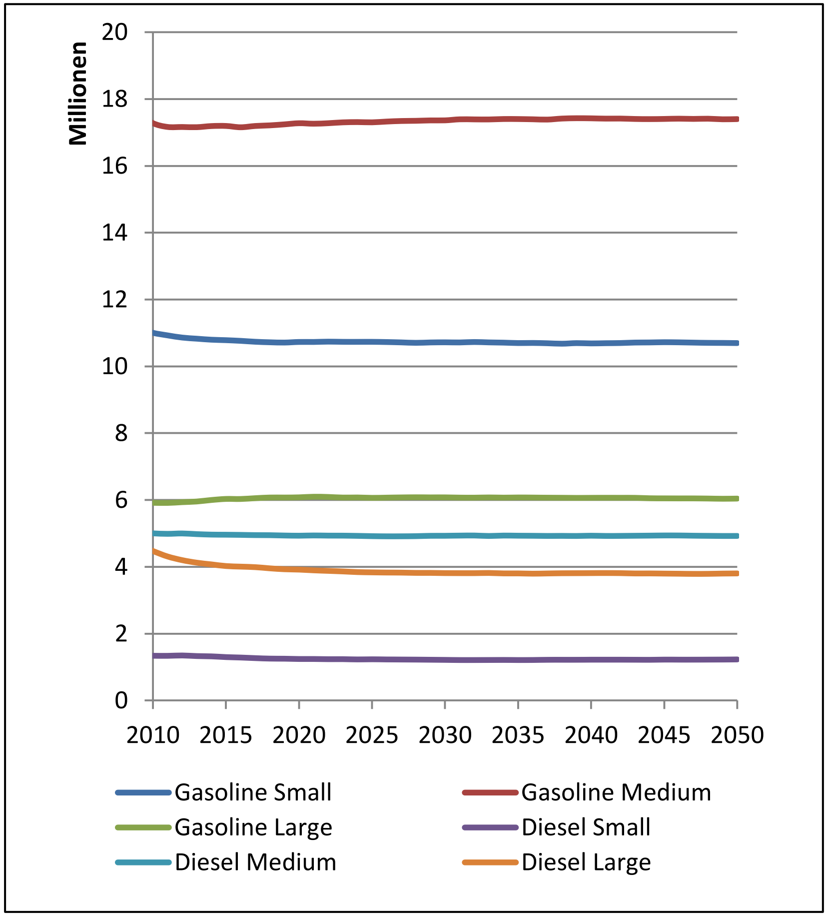
Calibration of CAST and control variables

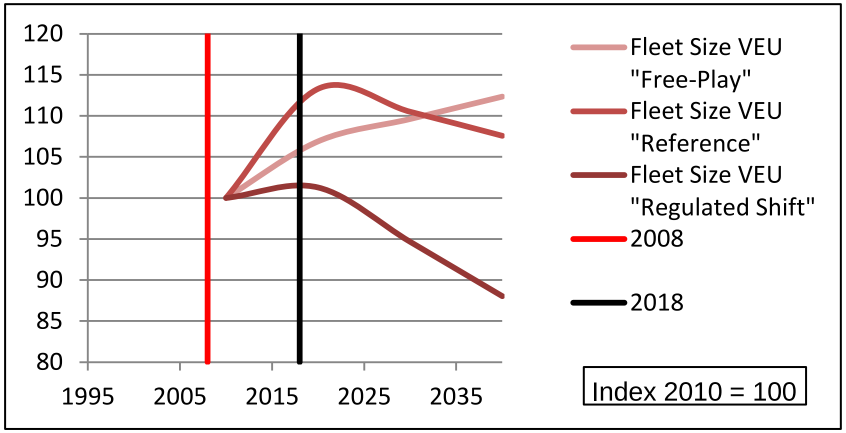
- Necessity of **external data sources** for **calibration**
  - MiD data has weaknesses concerning the total number of vehicles → **Iterative proportional fitting of the MiD** data for reweighting in advance of the pareameter estimation
- Use of **control variables** (data from KBA and DAT):
  - **Total 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**

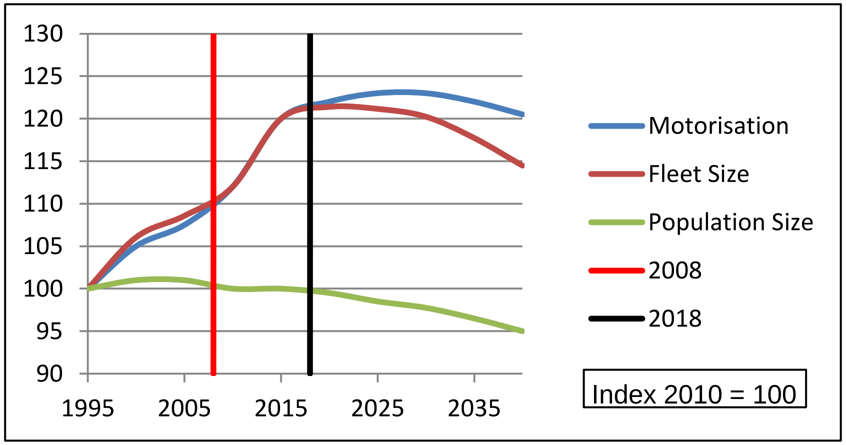
Excursus



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



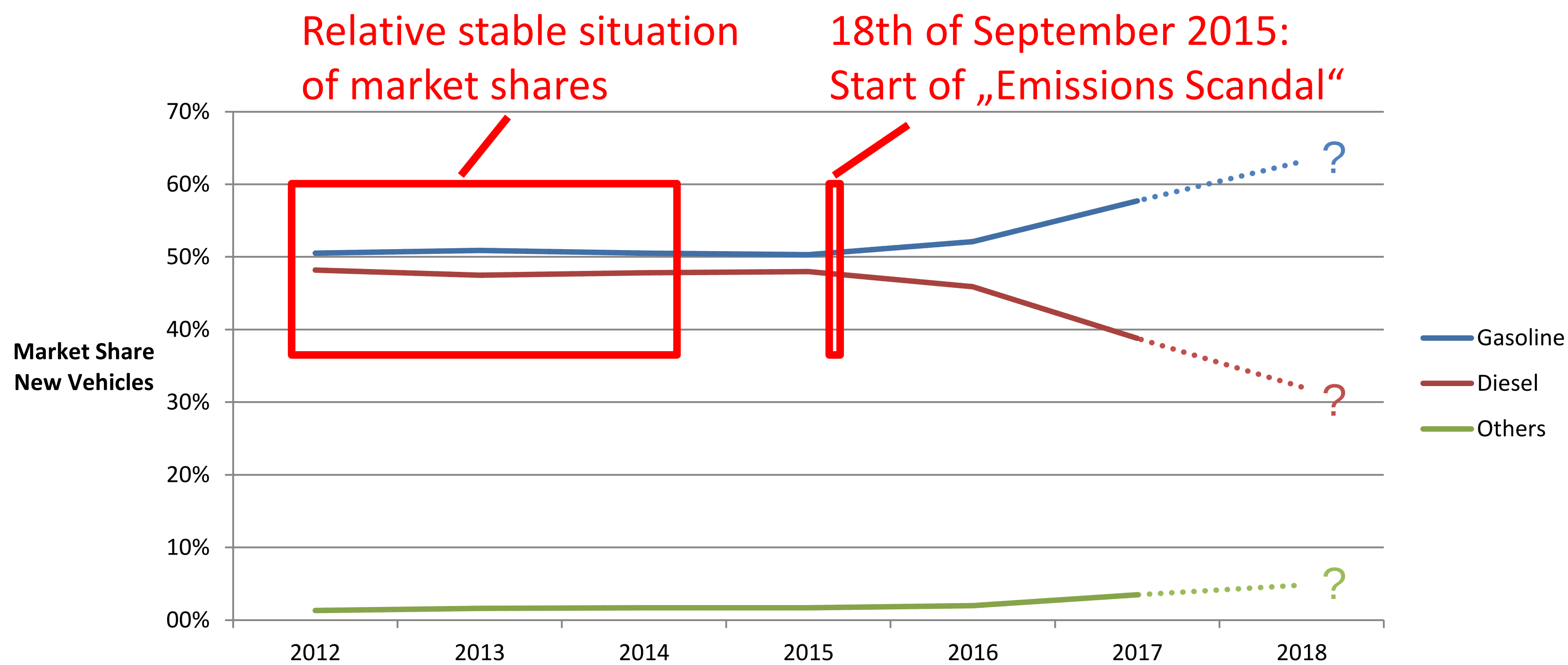
Scenarios from DLR-VF-Project VEU II (cf. Kugler et al. 2017)



Shell (2014)

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

Excursus



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)
    - **Addditional 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 conventionl 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%

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

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CAST: Scenarios

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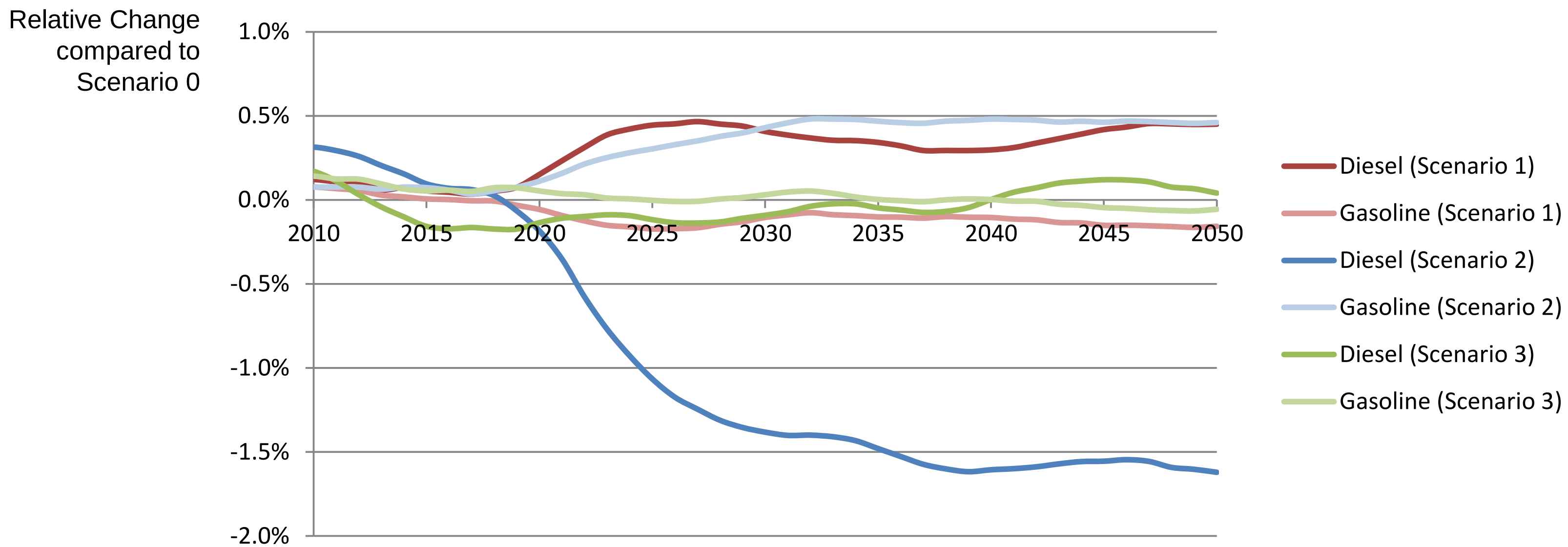

→ Scenario 1 emphasizes the necessity of the integration of the HouseholdSelector and the VehicleTechnologySelector (otherwise no effect on total Vehicle Fleet Size)

→ Effects in Scenario 1 and 3 rather low (However, the feasability of the policy in Scenario 2 is uncertain because of the effects on other economic sectors)

CAST: Scenarios

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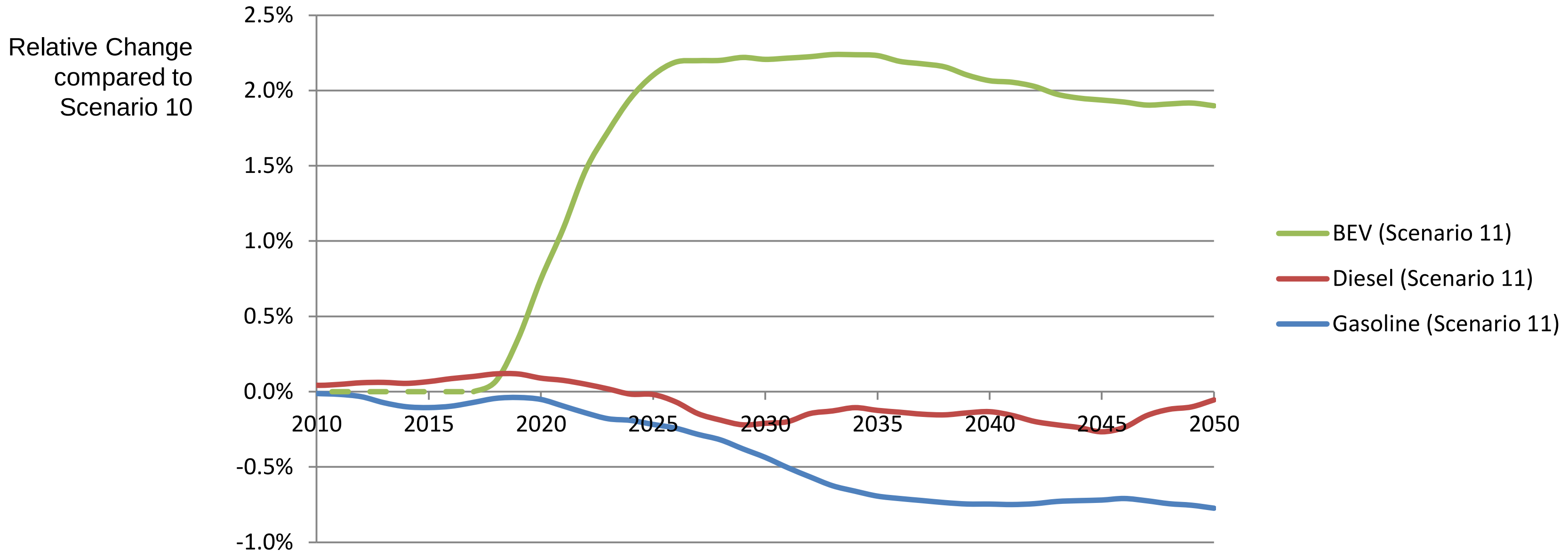
Scenarios 10-12: Introduction of BEVs as example for emerging technologies



→ 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

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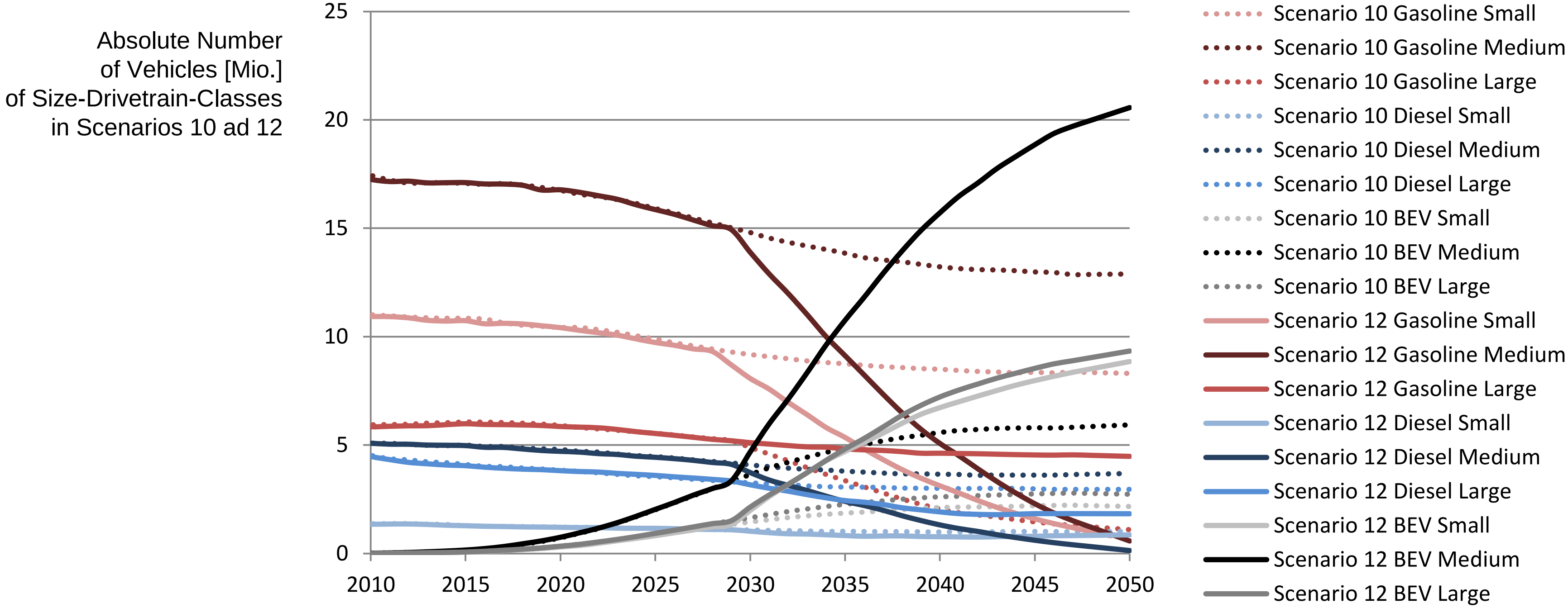

→ BEV-share in total Vehicle Fleet in Scenario 12 in 2050 at 88% compared to 25% in Scenario 10 (no adaption e.g. of the holding time distributions)

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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 applicacilty 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**

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