Agent-based simulation of emergence through monetary incentives and social pressure of green consumption patterns in car markets

19 Aug 2008

Peter de Haan, ETH Zürich

Institute for Environmental Decisions, Natural and Social Science Interface

Structure of presentation

- **Setting the scene:**
  Background, and importance of car purchases.

Background
and topic

New cars
and energy
efficiency

Consumer
and incentive
schemes

Simulating
effects of
incentives

Modeling
preference
changes

Summary and
Conclusions

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- **Setting the scene:**

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- **New cars and energy efficiency:**

  VW Golf is not the same as VW Golf.

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  Direct and indirect effects.

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- **Agent-based microsimulation:**
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- **Agent-based model:**

  Personal satisfaction vs. social influence

Background
and topic
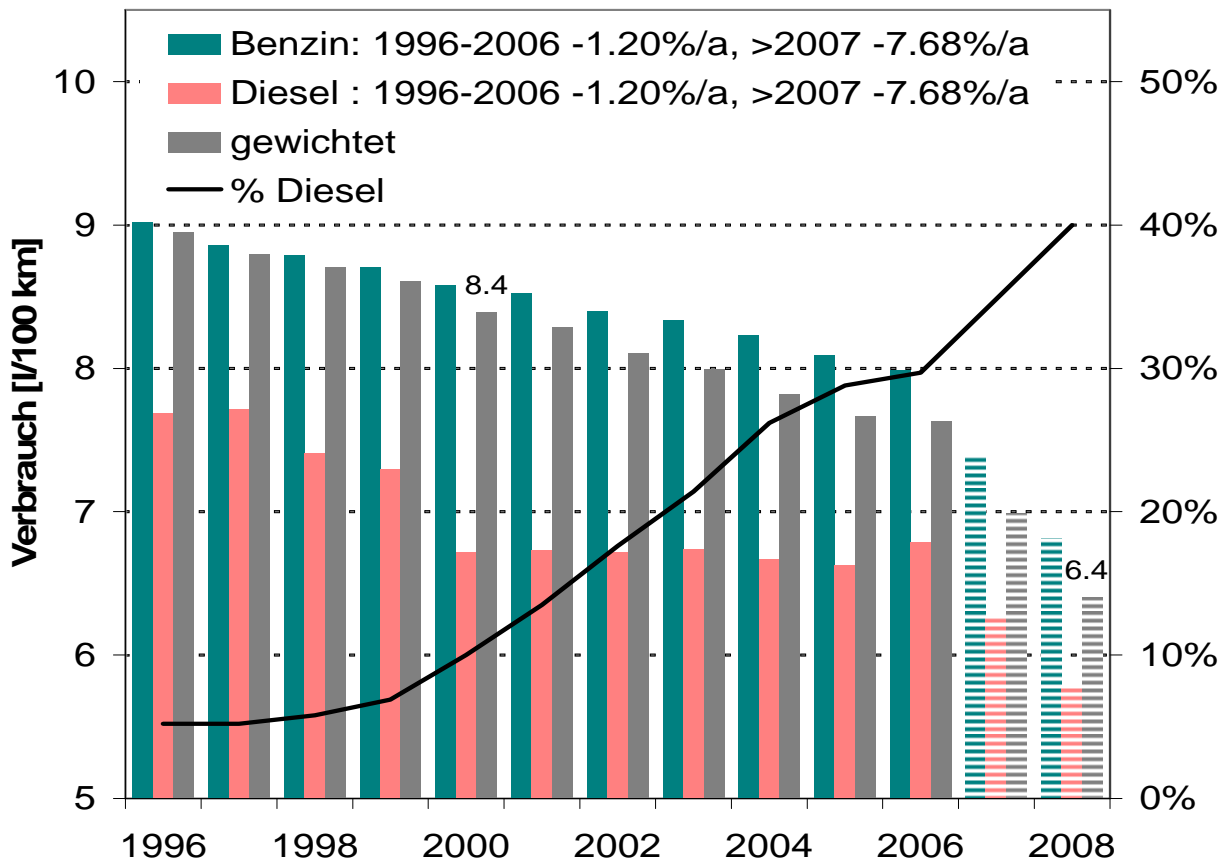
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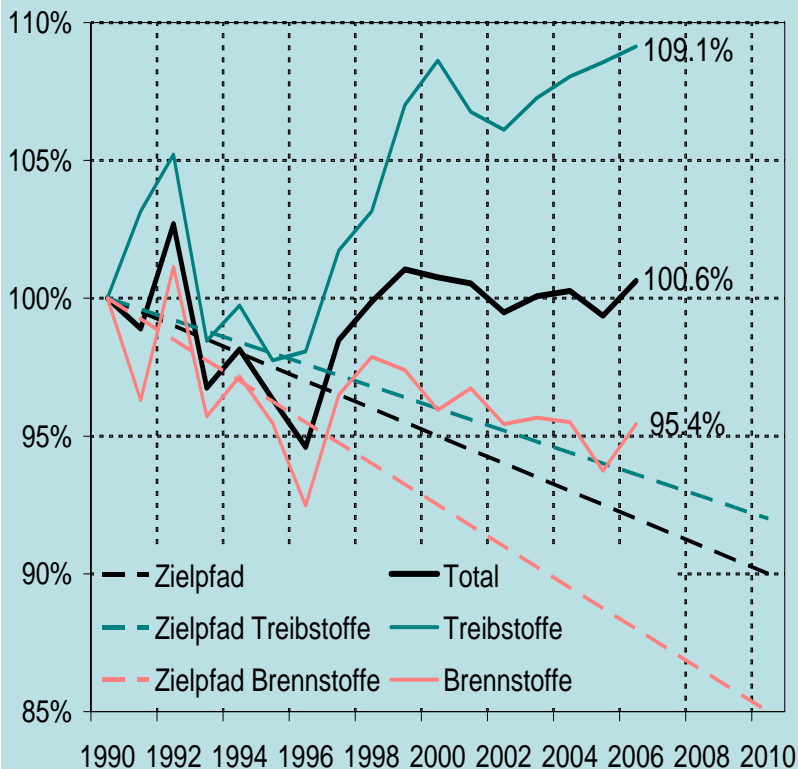
Topic: Reducing energy demand for cars

An consumer-driven environmental problem.

Technology is available.

Everybody agrees and knows what should be done.

Consumers apply strategies to cope with dissonance between norm and personal behavior („U.S. should start", „Switzerland is only small", „China is the new problem", „Car makers should build other cars", „First eliminate SUV's", „I personally cannot change anything", „Climate change not yet scientifically proven", *etc.*.

Need to show individual potential to consumers

Good news: Cars more efficient each year

Chart legend:
- Benzin: 1996-2006 -1.20%/a, >2007 -7.68%/a
- Diesel : 1996-2006 -1.20%/a, >2007 -7.68%/a
- gewichtet
- — % Diesel

Y-axis (left): Verbrauch [l/100 km], range 5 to 10
Y-axis (right): 0% to 50%
X-axis: 1996, 1998, 2000, 2002, 2004, 2006, 2008

Annotations: 8.4 (2000), 6.4 (2008)

← Decrease fuel consumption new registrations:
–1.2%/a (diesel)
–1.2%/a (gasoline)
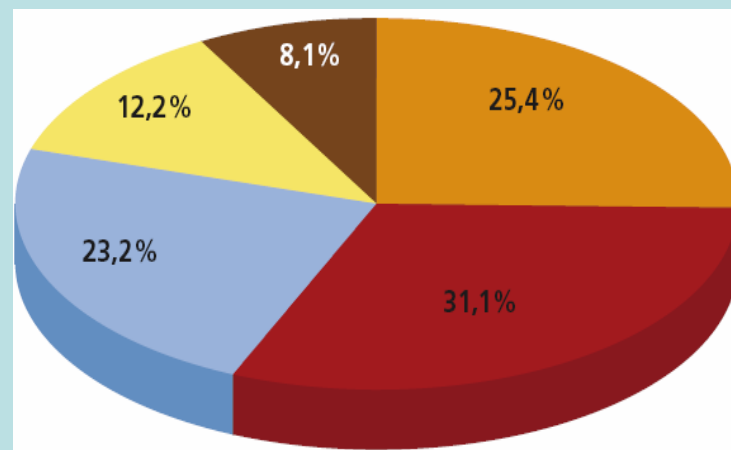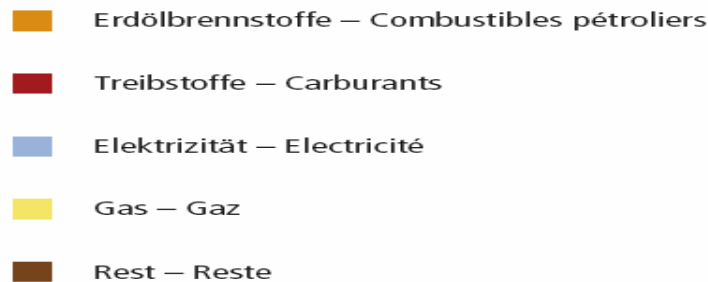
2006+07: Increase of fuel consumption for diesel cars due to particle filters

Background and topic

Bad news: More energy for cars each year

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CO₂ transport fuels: +9.1% since 1990

- Zielpfad — Total
- Zielpfad Treibstoffe — Treibstoffe
- Zielpfad Brennstoffe — Brennstoffe

Energie für Treibstoffe: 31.1%

Energie-Endverbrauch CH 2005

- Erdölbrennstoffe — Combustibles pétroliers
- Treibstoffe — Carburants
- Elektrizität — Electricité
- Gas — Gaz
- Rest — Reste

EU commission: Three pillar strategy.

COM(95)689: Community Strategy to Reduce CO_2 Emissions from Cars and to improve fuel-efficiency;

- Pillar 1: Voluntary agreements
  (140 g/km until 2008/09)
  (130 g/km until 2012?)

- Pillar 2: Energy/CO_2 labeling
  (voluntary: categories A–G)

- **Pillar 3:**
  Fiscal measures/ incentive schemes
  (NL, B, UK, A, P, DK, S, I, F, L, CY)

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Energy demand: OECD will be overtaken by developing countries in 2014

- Today: 20% of world population = 80% of energy

-

Autos/1000 Einw.	
USA	759
Luxemburg	659
Italien	581
Deutschland	546
CH	514
Österreich	501
EU25	472
China	2

Eurostat 2006
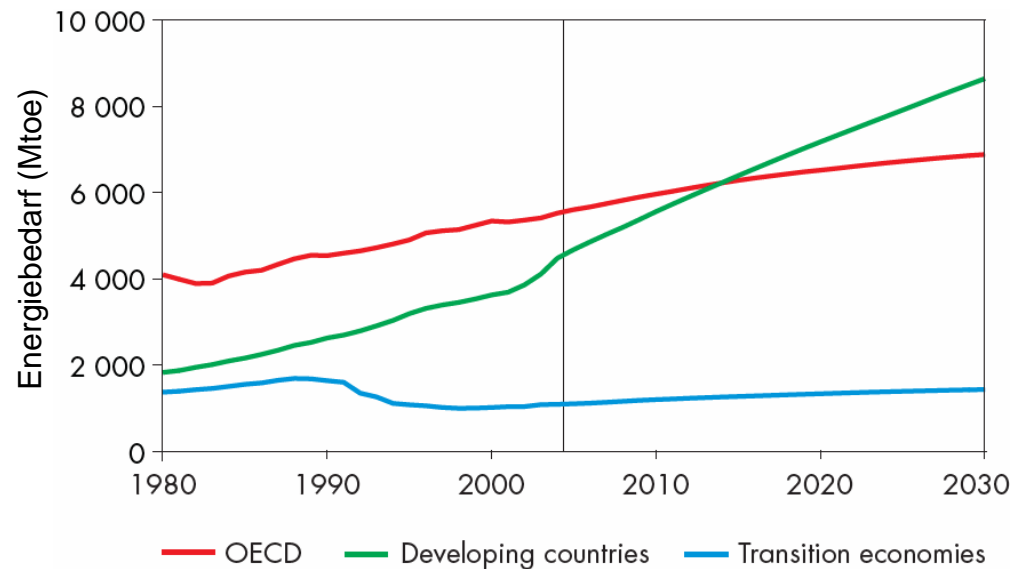
Figure 7.14: Global Savings in CO$_2$ Emissions in the Alternative Policy Scenario Compared with the Reference Scenario

Alternative policy scenario: fossil fuels +37% until 2030 (instead of +50%)
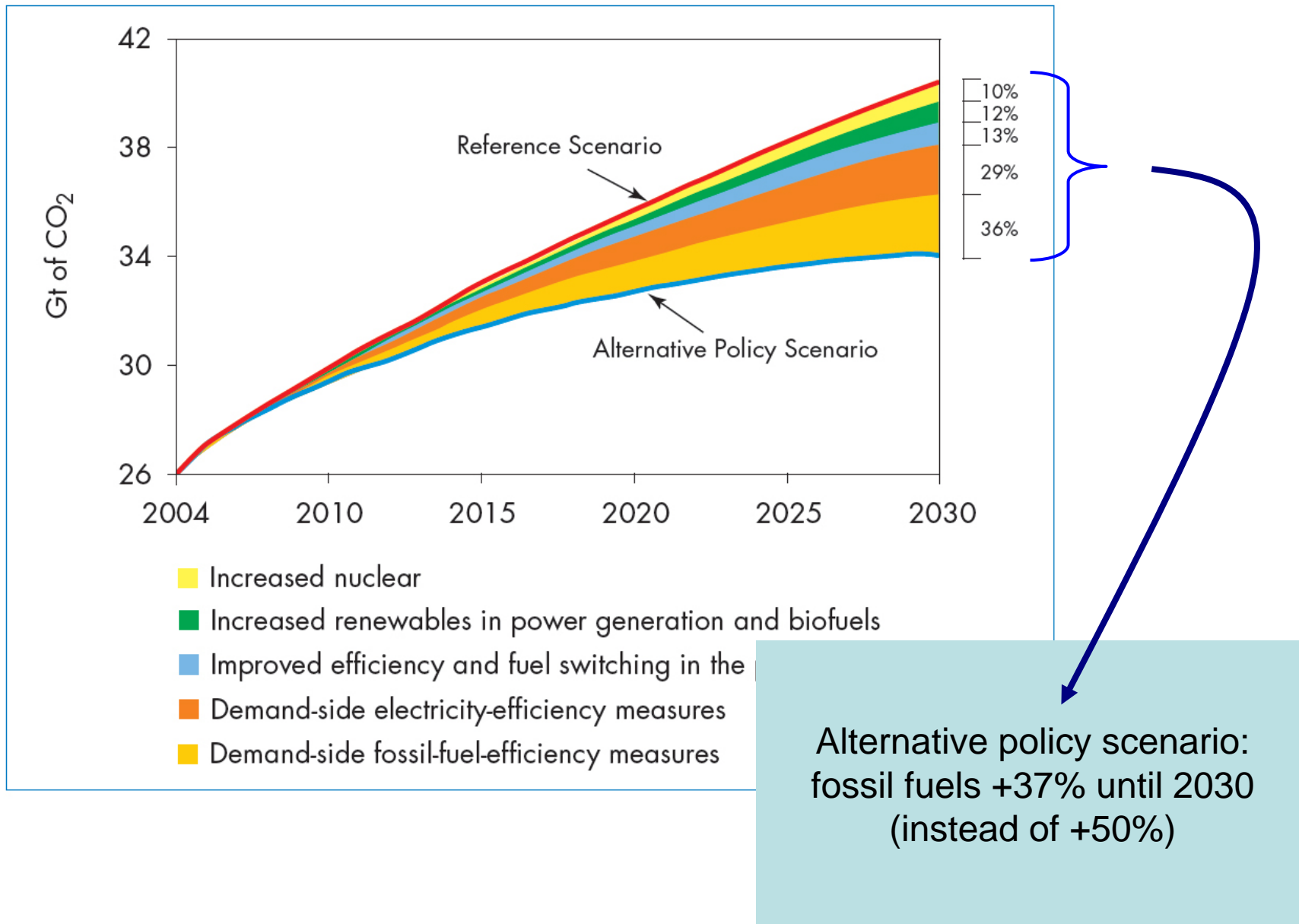
Shell/VW fuel strategy
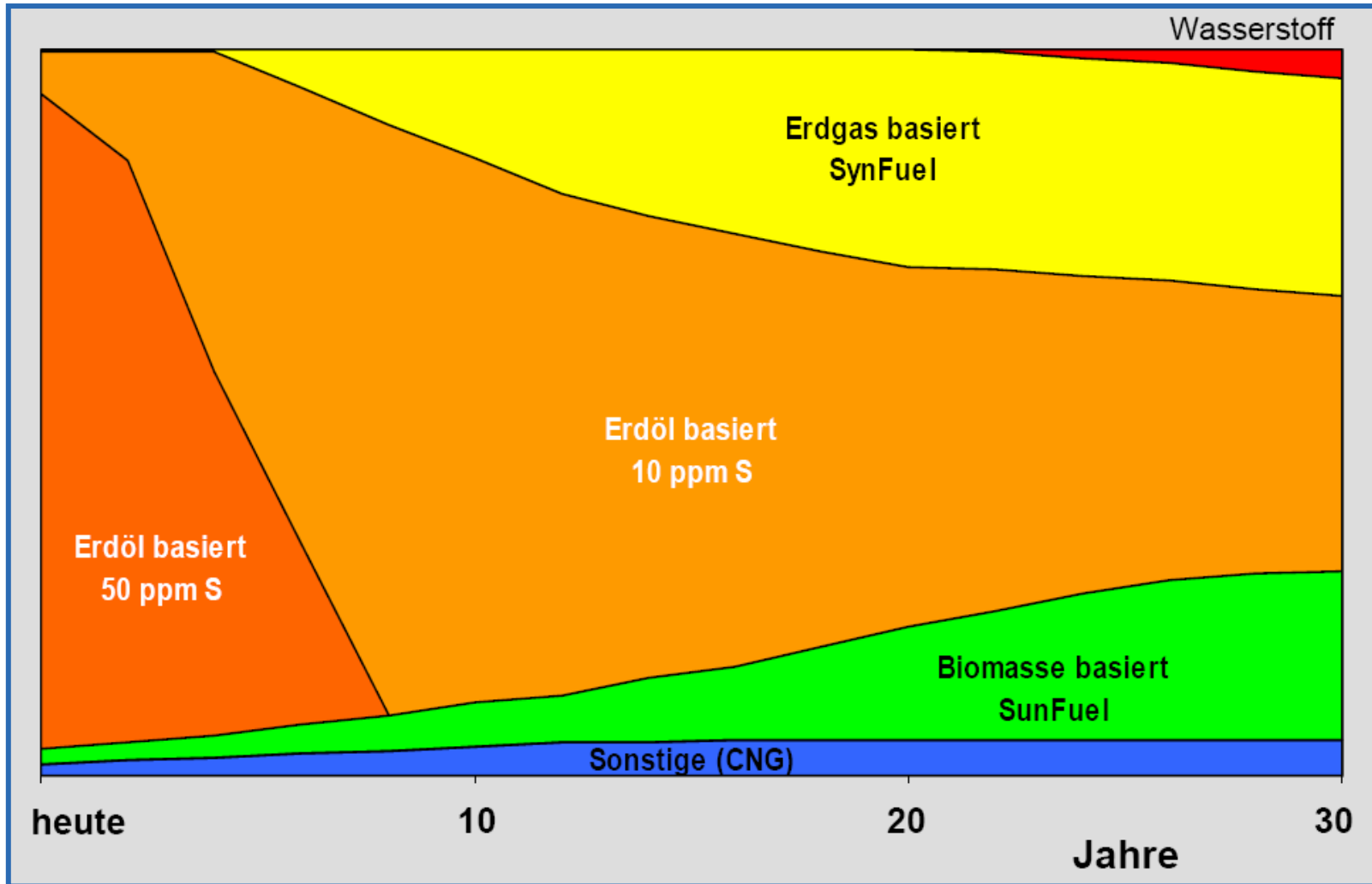
The traditional approach

- Cars are technically optimal

- Energy saving through either

  route a) smaller cars/less mileage, or

  route b) improved technology (lightweight materials, hybrid)

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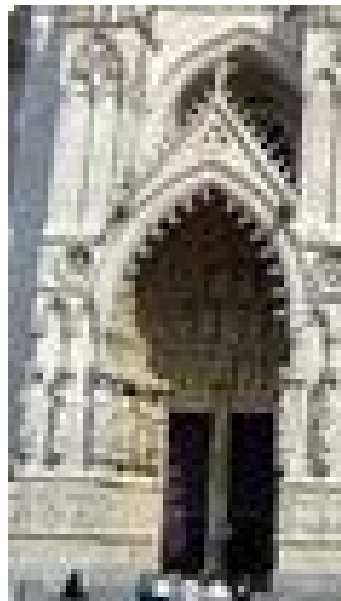
...but today's presentation is on...

route a)
smaller cars/
less mileage

**route c)
smaller
engines**

route b)
improved
technology

inefficient car

fuel-efficient car

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Same car, same size
large differences in CO$_2$ emissions:
It is up to the consumer…

VW Golf 1.9 TDI Comfortline,

5.0 Liter diesel/100 km,

142 g CO$_2$/km (w. particle filter)

Efficiency category A

+40%

VW Golf 2.0 FSI Comfortline,

8.3 liter gasoline/km,

199 g CO$_2$/km

Efficiency category D

Quelle: zum Verkauf stehende Neuwagenflotte per 09.2006, www.energieetikette.ch
N.B.: umwillen zweifelsfreier Vergleichbarkeit wurden GT-, GTI-, R32-, Plus- und Allradausführungen nicht betrachtet.

15 most sold car models: The engine is relevant for CO_2 emissions, not car size!
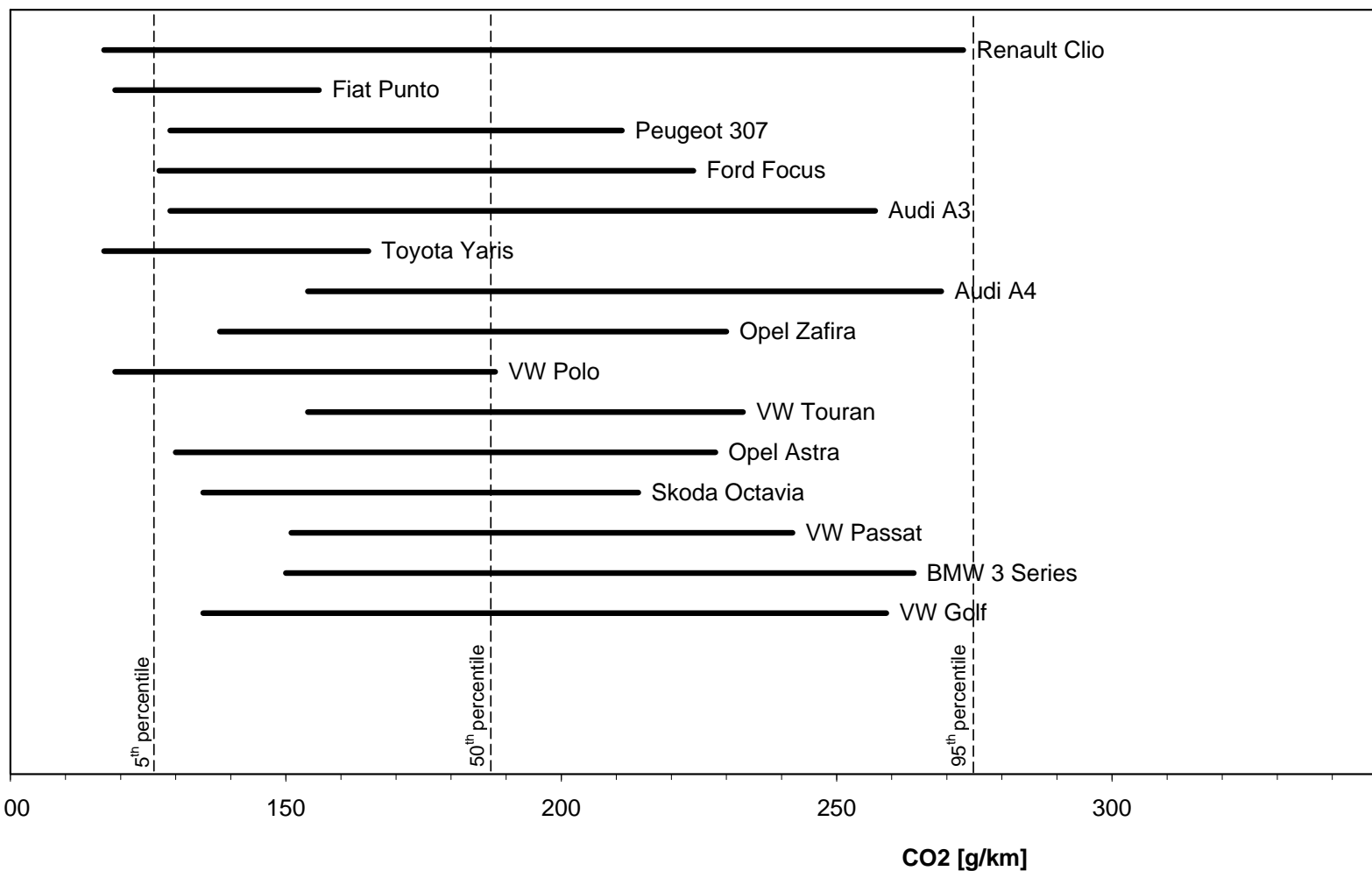
Overpowered cars in daily traffic

- 45 kW (55 h.p.) are sufficient for 160 km/h (1.5 tons)

- 0 to 100 km/h in 10 seconds: 110 kW needed
  (= ca. Swiss market average 2005)

- Engines are not optimal for daily traffic (engine map areas with low efficiency η)

Bereich $\eta > 30\%$

Typischer Betriebsbereich

Drehmomentreserve
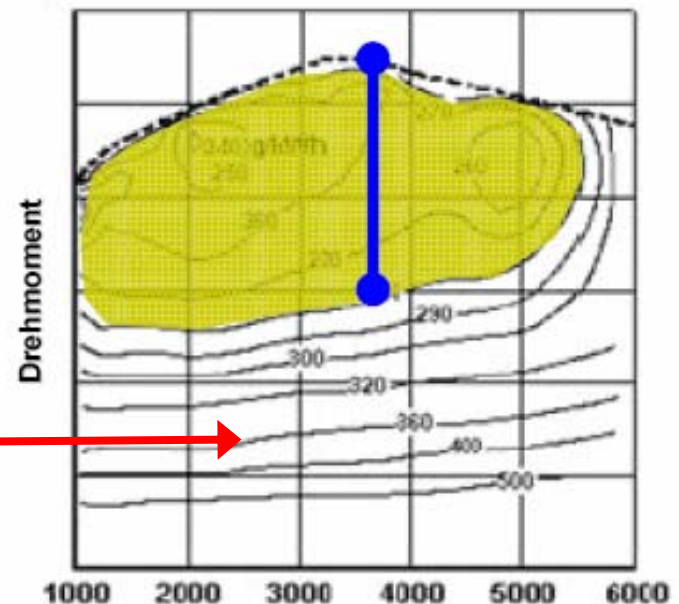
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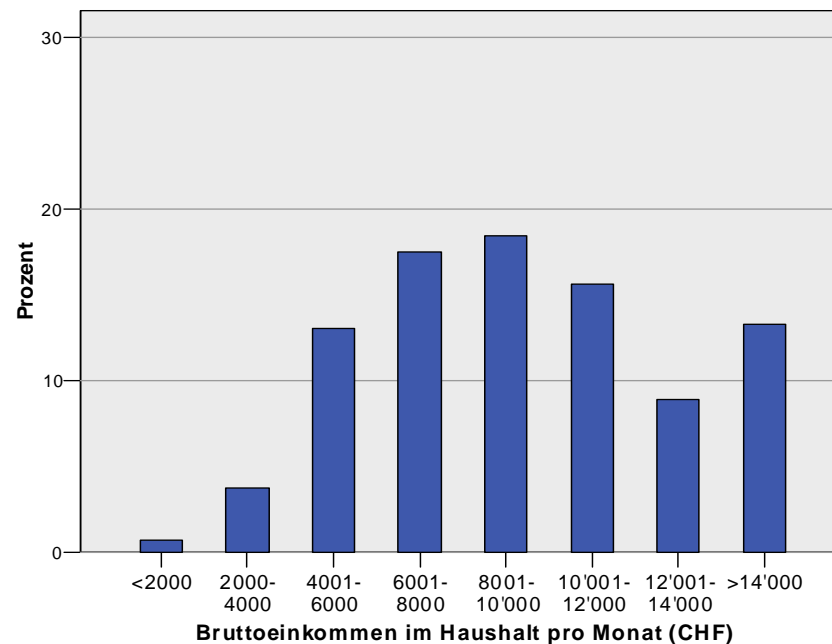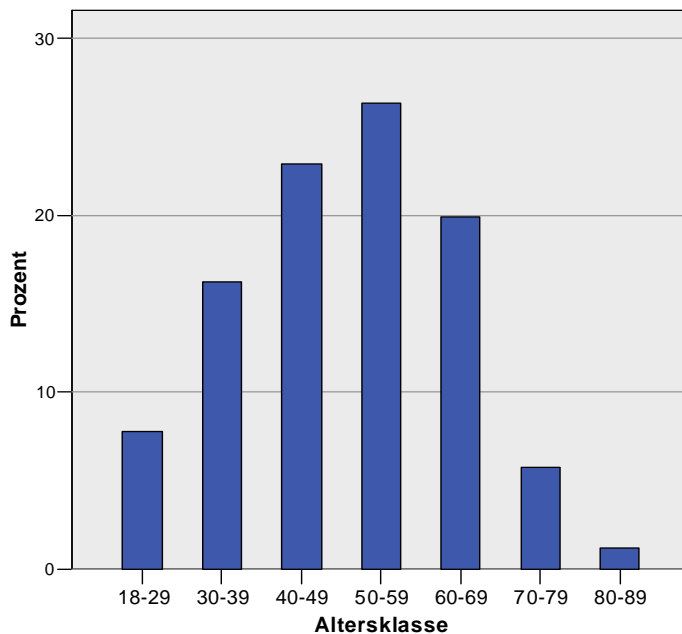
Summary and Conclusions

28 tons
22'000 ccm
440 h.p.

2 tons
6'000 ccm
??? h.p.

8 tons
12'000 ccm
430 h.p.

28 tons
22'000 ccm
440 h.p.

2 tons
6'000 ccm
450 h.p.

8 tons
12'000 ccm
430 h.p.

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Buying a new car means deciding for 3 other households as well!

- Lifetime of cars: 11 years (increasing)

- Mileage: > 160'000 km (increasing)

- Each car is sold up to 3x als second-hand car

- First owner on average only drives half the miles

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The typical Swiss new car buyer…

- … is 73.9% male
- … is 50.1 years old
- ... lives in household with income € 5300 – € 7000
- … owns 1.47 cars

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- € 2000 für „A"-labeled cars

- Financed by general increase of sales tax (i.e. import tax):

➔ no massive market impact

➔ no large changes in car size distribution expected

➔ focus on engine power (more efficient enginces)
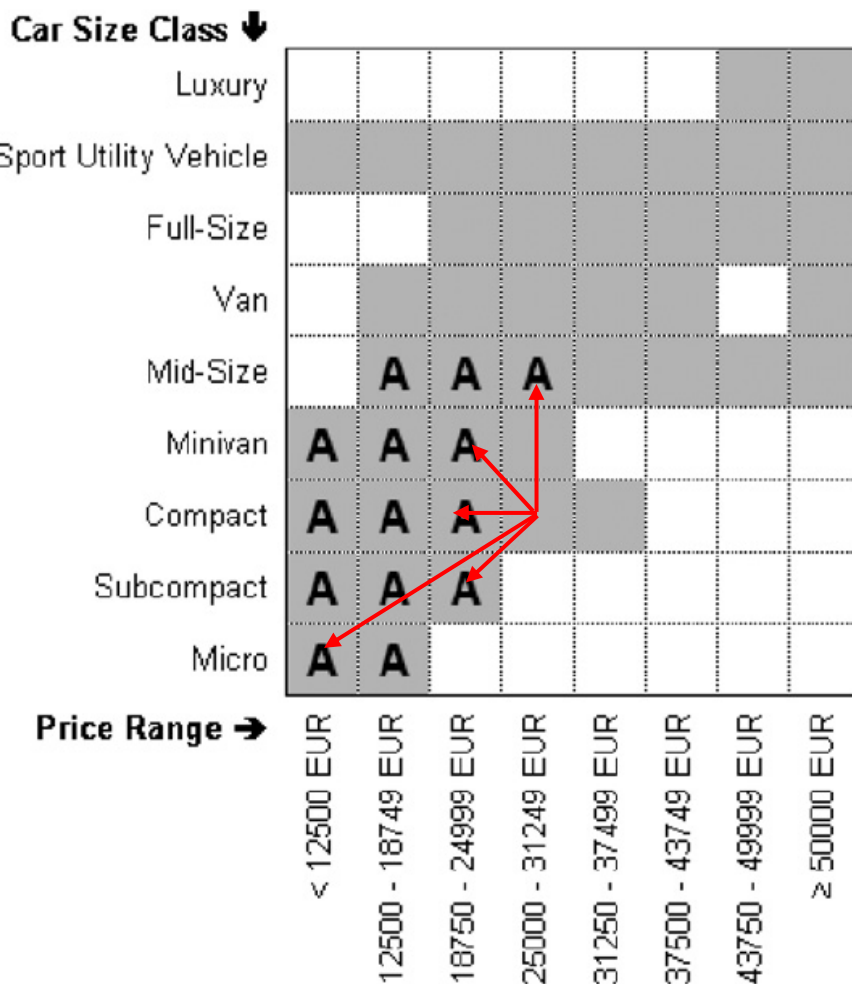
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Under incentive schemes, consumers have several options to react

Car Size Class ⬇

- smaller car
- completely diff. car
- smaller engine
- switch fuel type
- any combination
- ➔ need for microsimulation
- (do nothing)

How incentives take effect:
(a) Direct effect on demand side

monetärer Anreiz / Subvention /
differenzierte Besteuerung /
Lenkungsabgabe

direkte Wirkung

Konsumenten reagieren auf Preissignal

How incentives take effect :
(b) Macro-effects (adjustment on supply side)

monetärer Anreiz / Subvention / differenzierte Besteuerung / Lenkungsabgabe

direkte Wirkung → Konsumenten reagieren auf Preissignal

Wirkung auf Makro-Ebene → Hersteller produzieren andere Autos

How incentives take effect :
(c) Indirect effects on consumer side

indirekte Wirkung auf Konsumentenseite

Änderung Verhalten + Präferenzen

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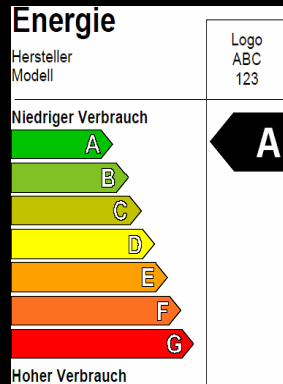
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Energie

Hersteller
Modell

Logo
ABC
123

Niedriger Verbrauch

A
B
C
D
E
F
G

A

Hoher Verbrauch

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ETH car market simulation model *sim*.car

2089 make-
model-engine
configuration

synthetic population
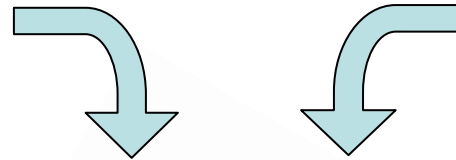
40 consumer groups

validation with
historical market
data 1998–2005

Forecast:
market share of
all 2089 car types

Detailed car fleet > choice of a subset (ruled by loyalty to brand, gear, size class)

2089 car models → **choice** → Choice set (1- 40 cars):
- Price
- Fuel costs
- Size
- Acceleration

Brand/gear/size loyalty ← **previous car**
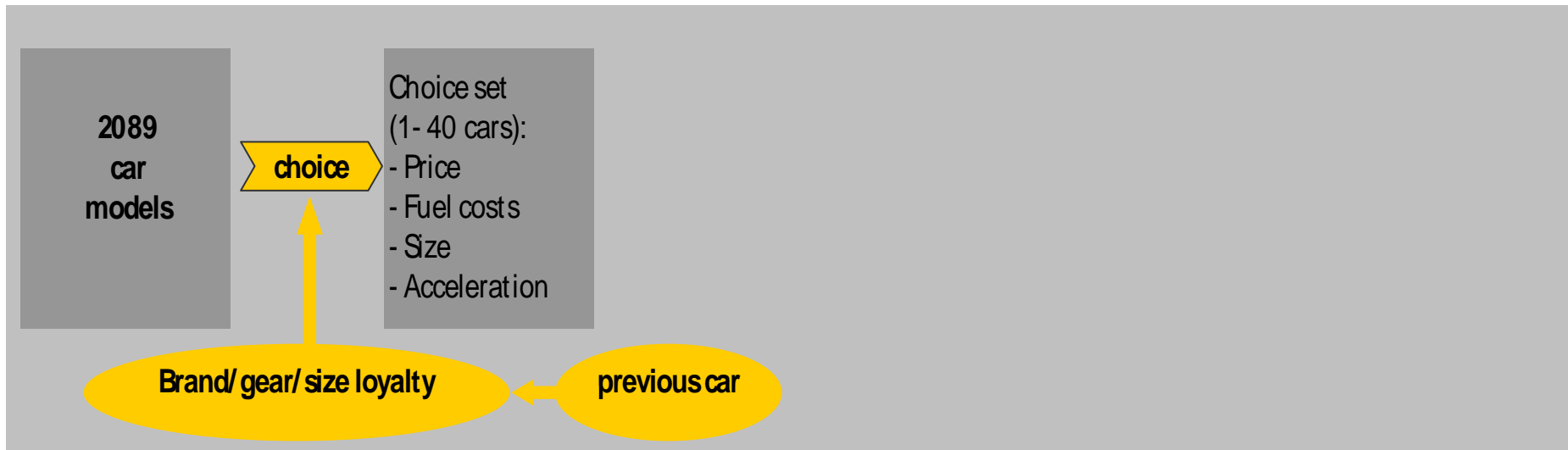
discrete choice model (multinominal logit)

2089 car models

choice

Choice set (1- 40 cars):
- Price
- Fuel costs
- Size
- acceleration

+

Bonus or penalty

Logit model

Brand/ gear/ size loyalty

previous car

bounded rationality

rational choice theory (utility maximization)
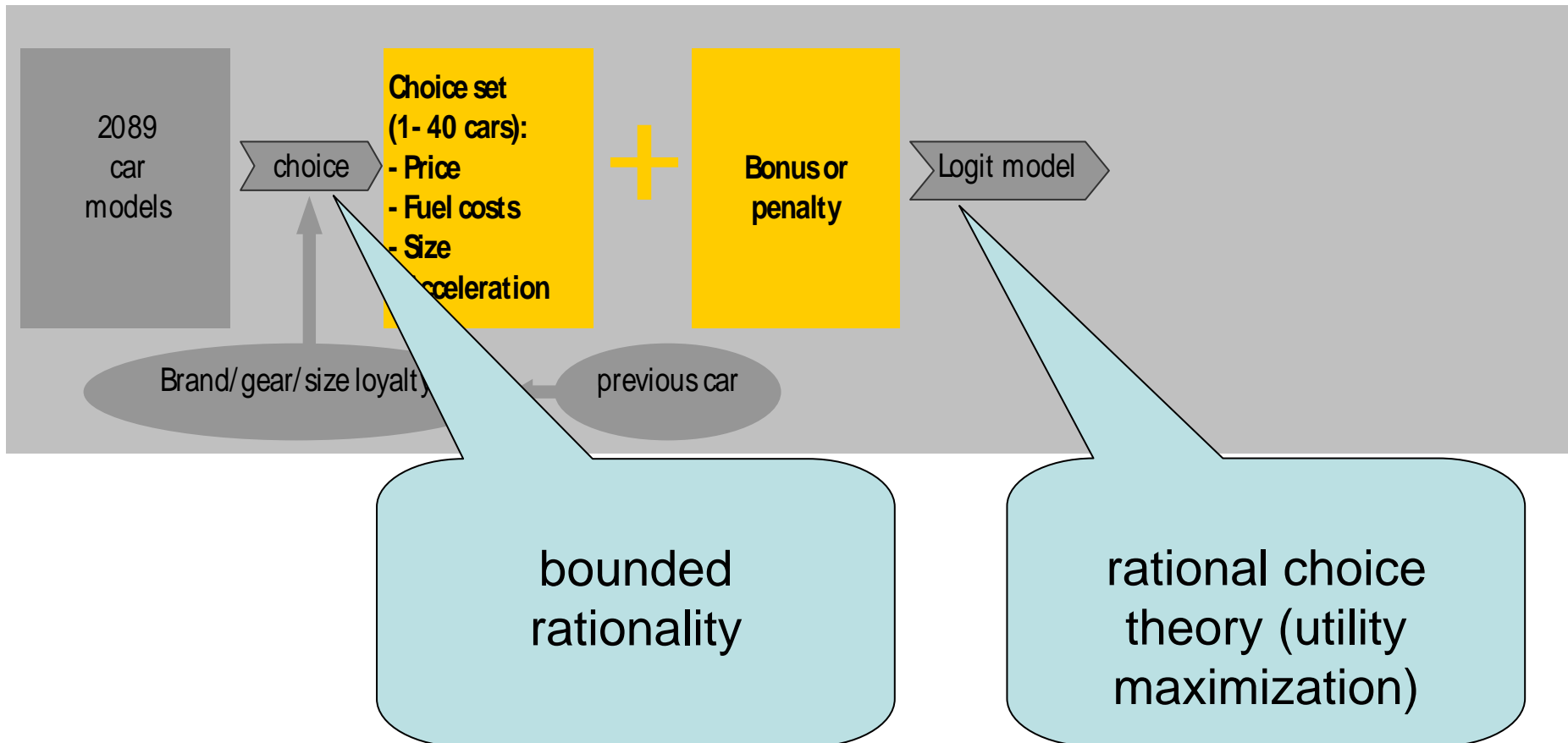
synthetic population out of census data (decision models for 40 groups)
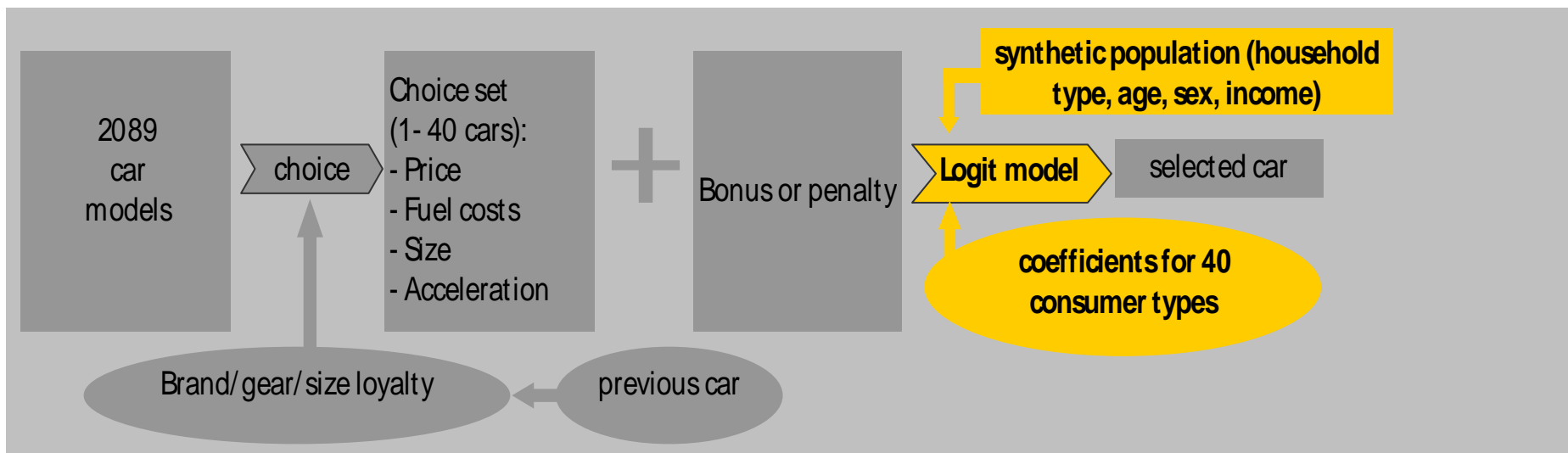
Bottom-up microsimulation (1 mio sales): Every statistic can be computed

Model is able to reproduce 2005 market data
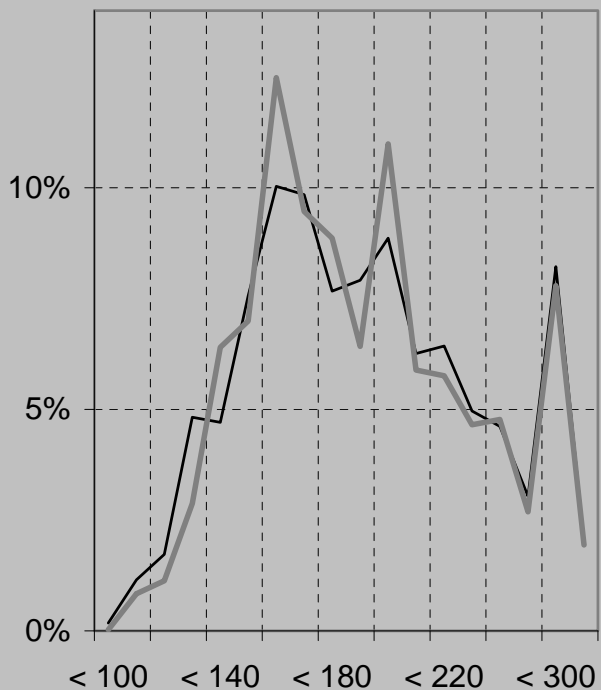
CO_2 Emission categories · **Efficiency cat., petrol** · **Efficiency cat., diesel**

Legend: market data CH 2005 / sim.car

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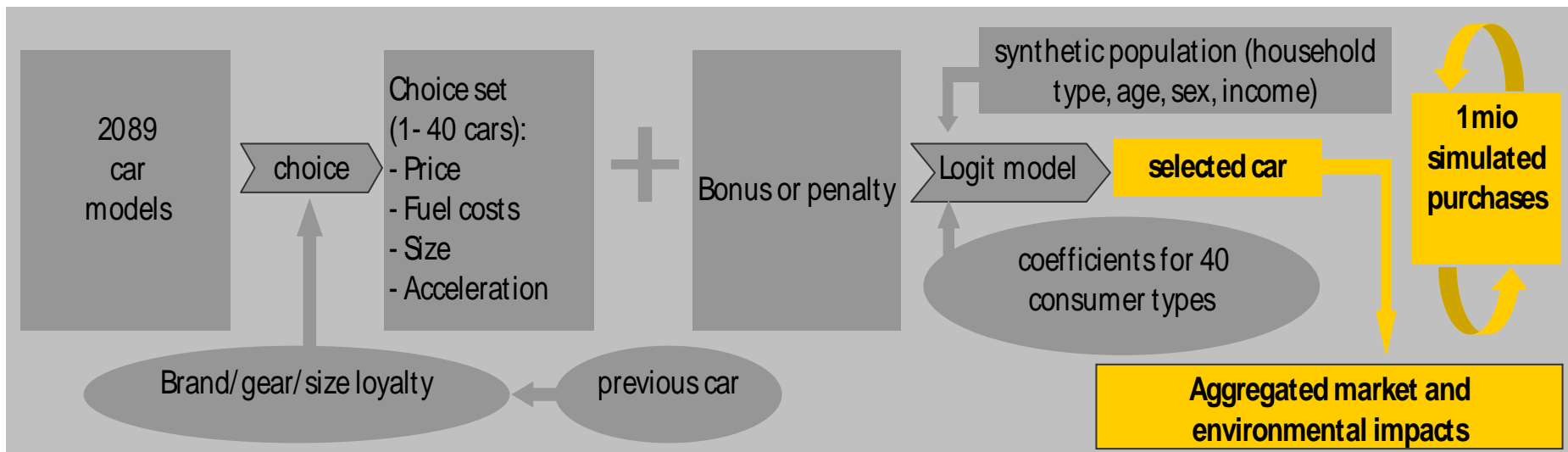Simulating effects of incentives

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Mueller, de Haan (subm.)
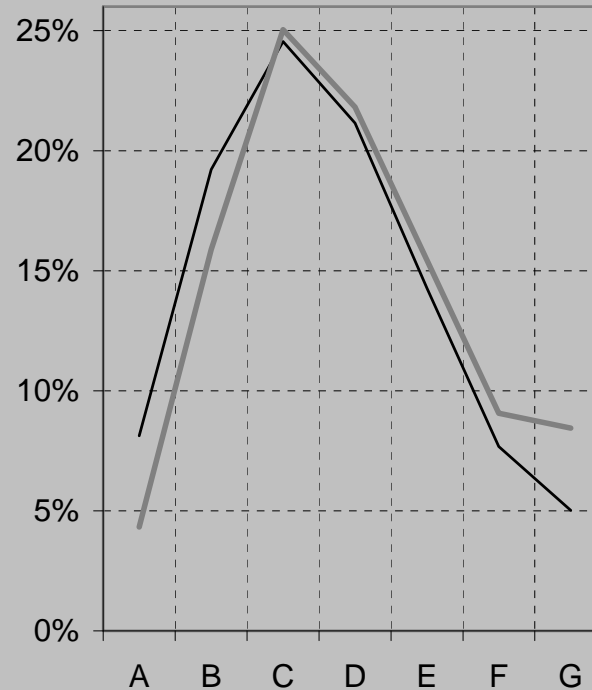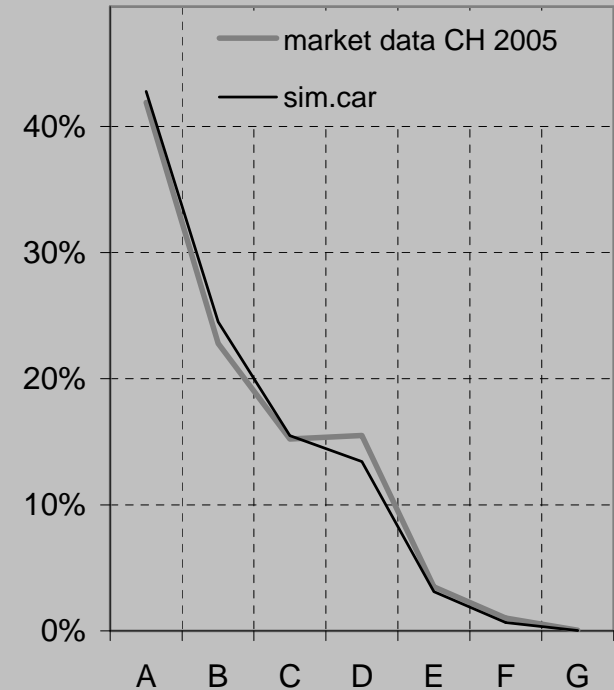
Effect of bounded rational decision phase

Random   **COWI (2002)**   **Bounded**

market share

CO_2 **emission categories** {<100 *g/km*; <120 *g/km*; <140 *g/km*; <160 *g/km*; <180 *g/km*; <200 *g/km*; <220 *g/km*; <250 *g/km*; <300 *g/km*; □300 *g/km*}

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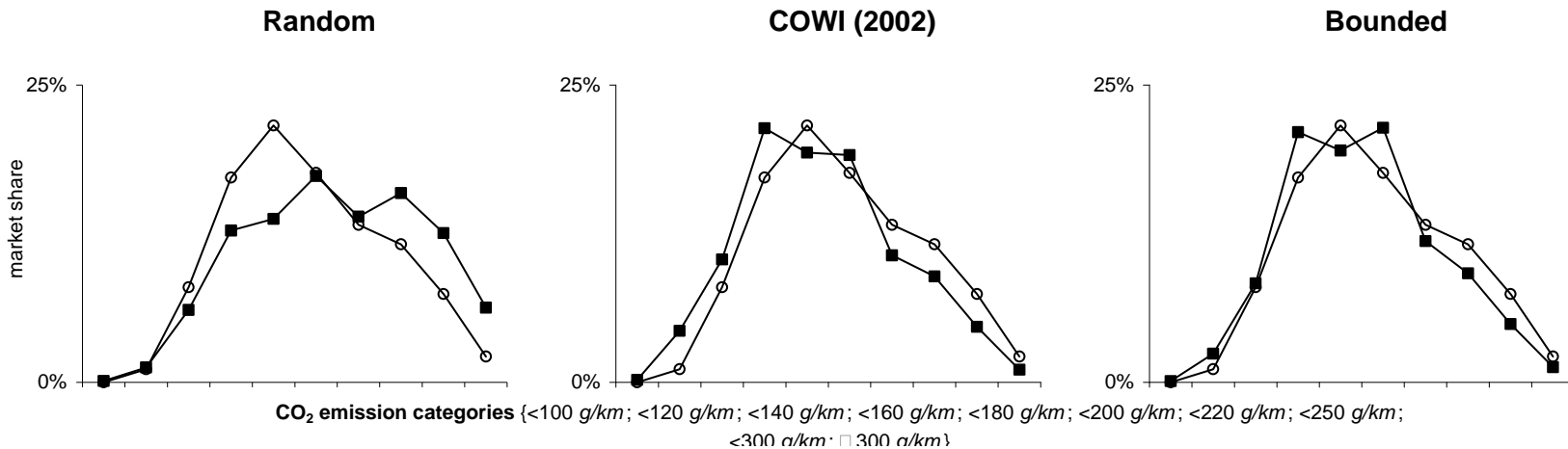
Model summary

Microsimulation of car market („microeconomic model with psychological effects") („data-driven"):

- 2000 car model versions

- 1 million agents, socio-demographics taken from census data; decision models for 41 groups

- influence of previously owned car (itteratively assigned, account for decision model, obeying marginal distributions from full market observation)

- random effects

- no neighborhood effects

- no changes in preferences or decision models

- able to reproduce historical market data with high precision

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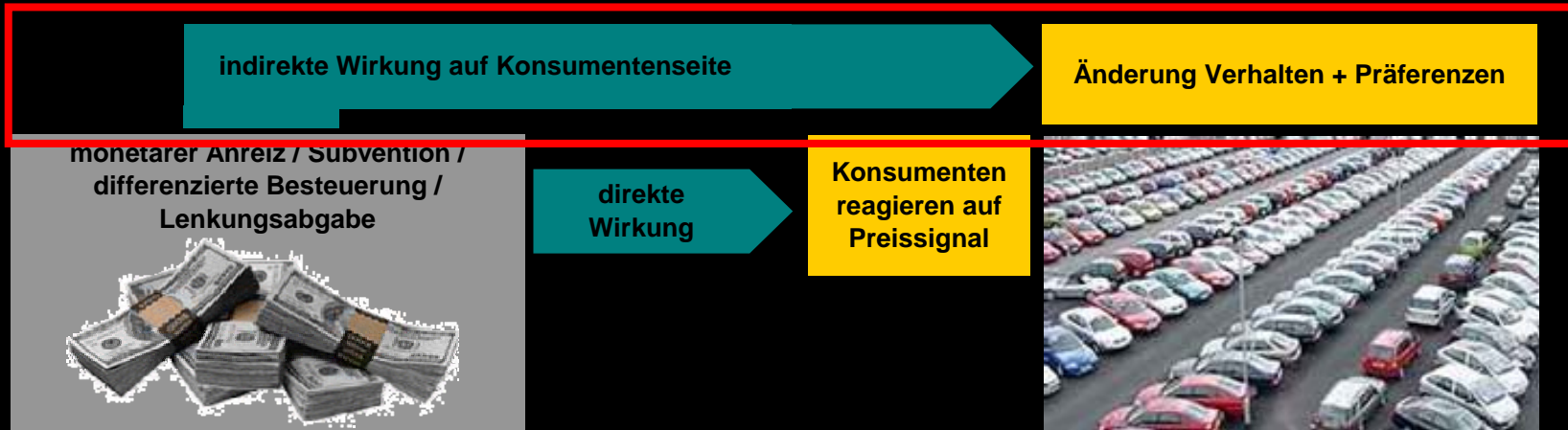
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A simple agent-based model on balance between personal preference and social norm

Corner stones

- Altruism vs. hedonism: „good" cars are less fun

- green consumption patterns may emerge even though individuals are in favor of environmental harmful products

- final goal: integrate neighborhood effects into microsimulation (to assess potential influence, even though we'll never know which numbers to plug in)

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A simple agent-based model on balance between personal preference and social norm

- 7 groups of cars from A (very energy-eff.) to G (highly inefficient)

- Agents: have preferences (A to G)

- New car purchase: utility depends on own preference and on deviation from behavior of neighbors
  α: weight of personal vs. social utility

$$U_i = \alpha \cdot |choice_i - pref| + (1-\alpha) \cdot |choice_i - neighbors|$$

- Model version with global social norm towards A

$$U_i = \alpha \cdot |choice_i - pref| + (1-\alpha) \cdot \begin{cases} choice_i - neighbors & (neighbors < choice_i) \\ 0 & otherwise \end{cases}$$
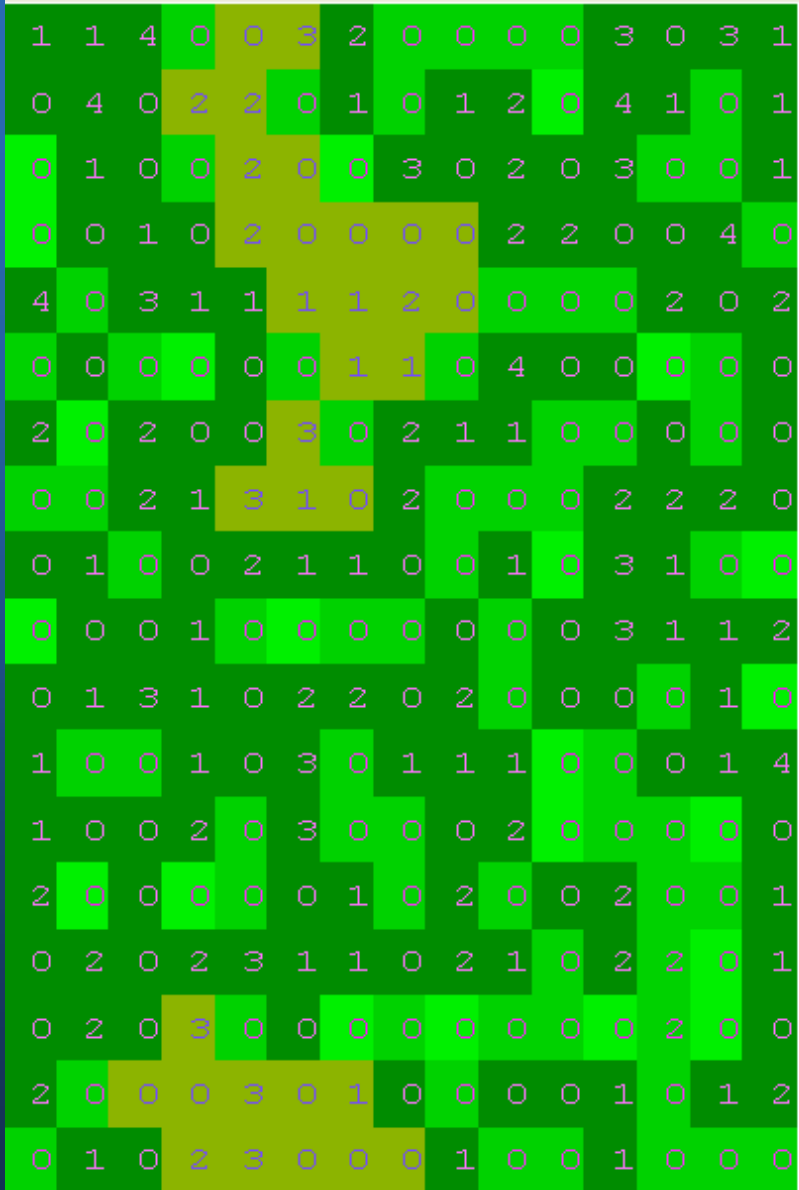
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"A"
cars

preference

actual
purchase
behavior

< more "C" cars sold due to
neighborhood effects

$\alpha = 0.49$:
hedonism
wins

$\alpha = 0.50$
with small
random
effects

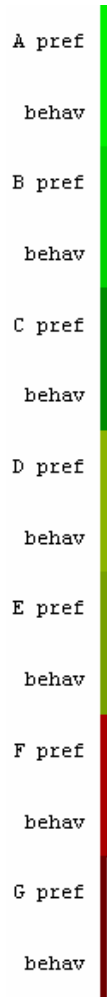$\alpha = 0.51$
altruism
wins

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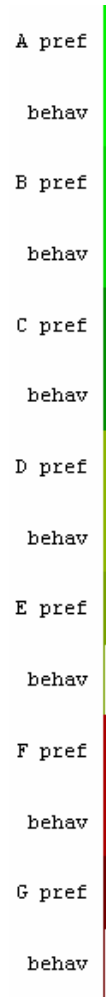
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$\alpha = 0.50$

with small

random

effects

$\alpha = 0.50$

with

diff.

initial

car

fleet

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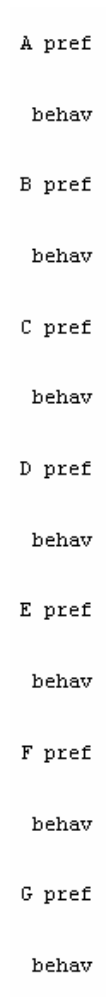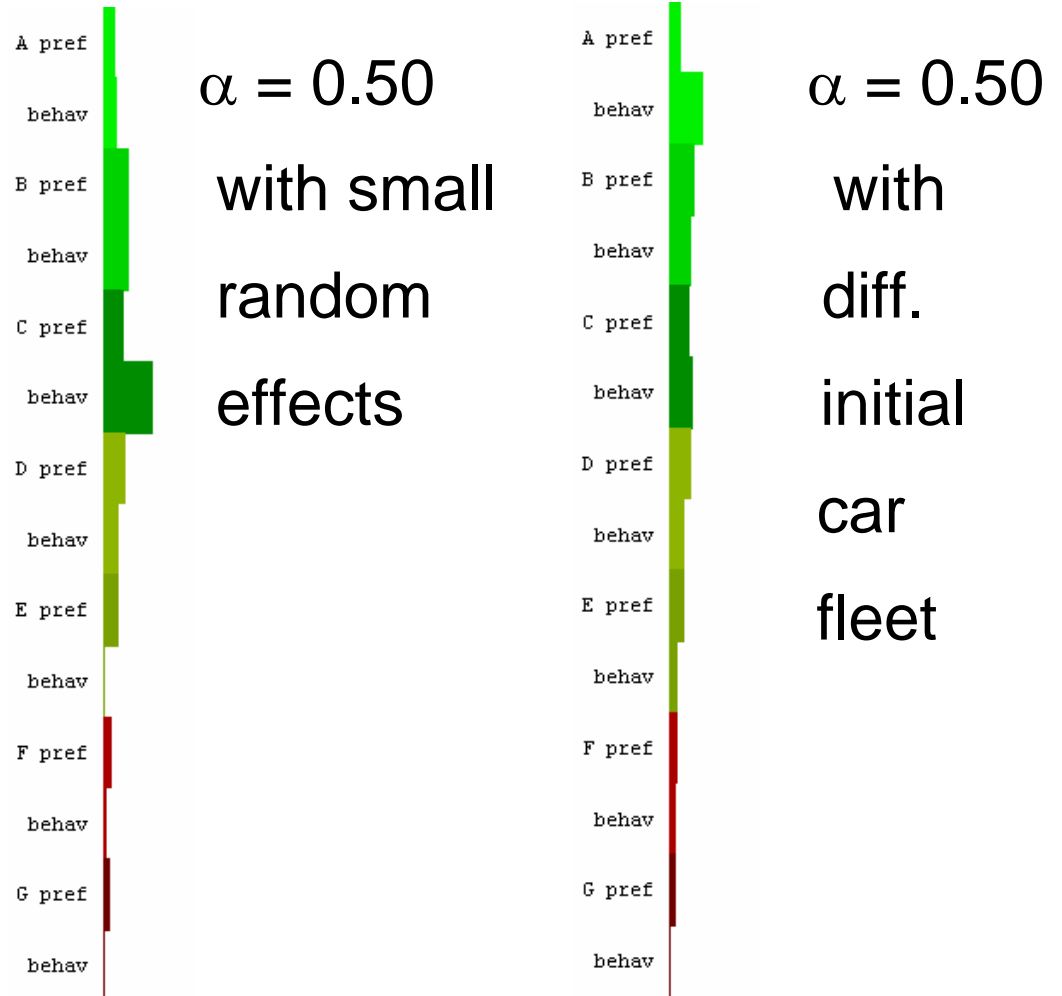Simulating
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Two equilibria: present situation, and „greener world". Exogenic forcing for transition needed

- another equilibrium present if the starting condition is different
  (people already own efficient cars)
  => once population has „switched" to more eff. cars,
    stable equilibrium without needing changed decision rules

- ➔ incentive schemes to induce switch to other equilibrium?
  (in line with insights:
  :: people base car purchase decisions on past experiences;
  :: people do not know anymore the power of car engine;
  :: incentives might motivate people to be better informed)

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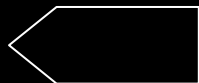
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Summary (1/2)

- High relevance of car purchase decision process:
  - Determines 30% von domestic energy demand and CO_2;
  - High reduction potential without reduction in car size!

- Need for very detailed representation of car model versions; need to allow for many behavioral options when reacting to incentive schemes
  ➔ microsimulation (microeconomic model with bounded rationality and allowing for non-linear effects)

- Problem: No changes in preferences; difficult to assess economic elasticity vs. possible market changes due to trends/changes in preferences.

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Summary (2/2)

→ Agent-based model to simulate hedonistic vs. altruistic trade-off in car choice

- Influence of initial car fleet owned by agents

- Plugging this into market microsimulation?

THANK YOU FOR YOUR ATTENTION