The Determinants of Energy Demand of the Swiss Private Transportation Sector

Summary

Carbon dioxide emissions from traffic contribute a high proportion of the total greenhouse gas emissions. Since due to some technological restrictions these emissions cannot be reduced as cost effective as in the case of housing, to look at the emissions from traffic is particularly important. In the following, I aim to identify the determinants of fuel demand. Since the fuel demand depends mainly of the households with respect of their car use, I need a microeconomic model. Since so far no traditional microeconomic model maps all relevant factors in an adequate way, I decided to derive our own model. Our model is based on the Multiple Discrete-Continuous Extreme Value Model (MDCEV) first introduced by Bhat (2005). This model maps a number of quantities of different goods a household may consume and includes the case where households do not consume certain goods at all. I adapt this model to the case where households may choose between several car types including the cases where households decide to be carless or owning several cars. To do so, I introduce – as a novelty – fixed cost of car ownership to this model. So far, no existing model can adequately map the impact of these fixed costs on car ownership and use.

In the following I present the model in its most simple form where households may only choose between being carless or owning one car. By use of this model I could already compute a number of interesting and important results. For instance I could show that the effect of a fuel tax on aggregate driving demand is rather dominated by households keeping their car and reducing the annual mileage than of households selling their car. Or I could show that a fuel tax is – per unit of tax revenue – more effective than a tax on car ownership with respect to the total annual car mileage. On top, since this model is based on a utility function, I can also compute for each household by how much additional income it needs to be compensated for a given level of fuel tax so that its utility remains unchanged. This possibility allows policy makers to identify tax reimbursement schemes so that a majority of voters profits from introducing a tax on fuel.

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Contents

1. Scope and Motivation

- Identifying the determinants of fuel demand
- Relevance of the subject with respect to carbon dioxide emissions
- Why examining carbon dioxide emissions of the private transportation sector?
  - Switzerland misses emission targets
  - Transportation sector contributes a high share and its emissions increase
  - Households contribute the main share of the emissions of the transportation sector
- Application: Examining the effects of the following policies

  i.) a fuel tax

  ii.) a tax on car ownership

  on

  a.) annual mileage of cars

  b.) car ownership and the share of carless households

  c.) car choice with respect to fuel efficiency

- Carbon dioxide emissions of the transportation sector

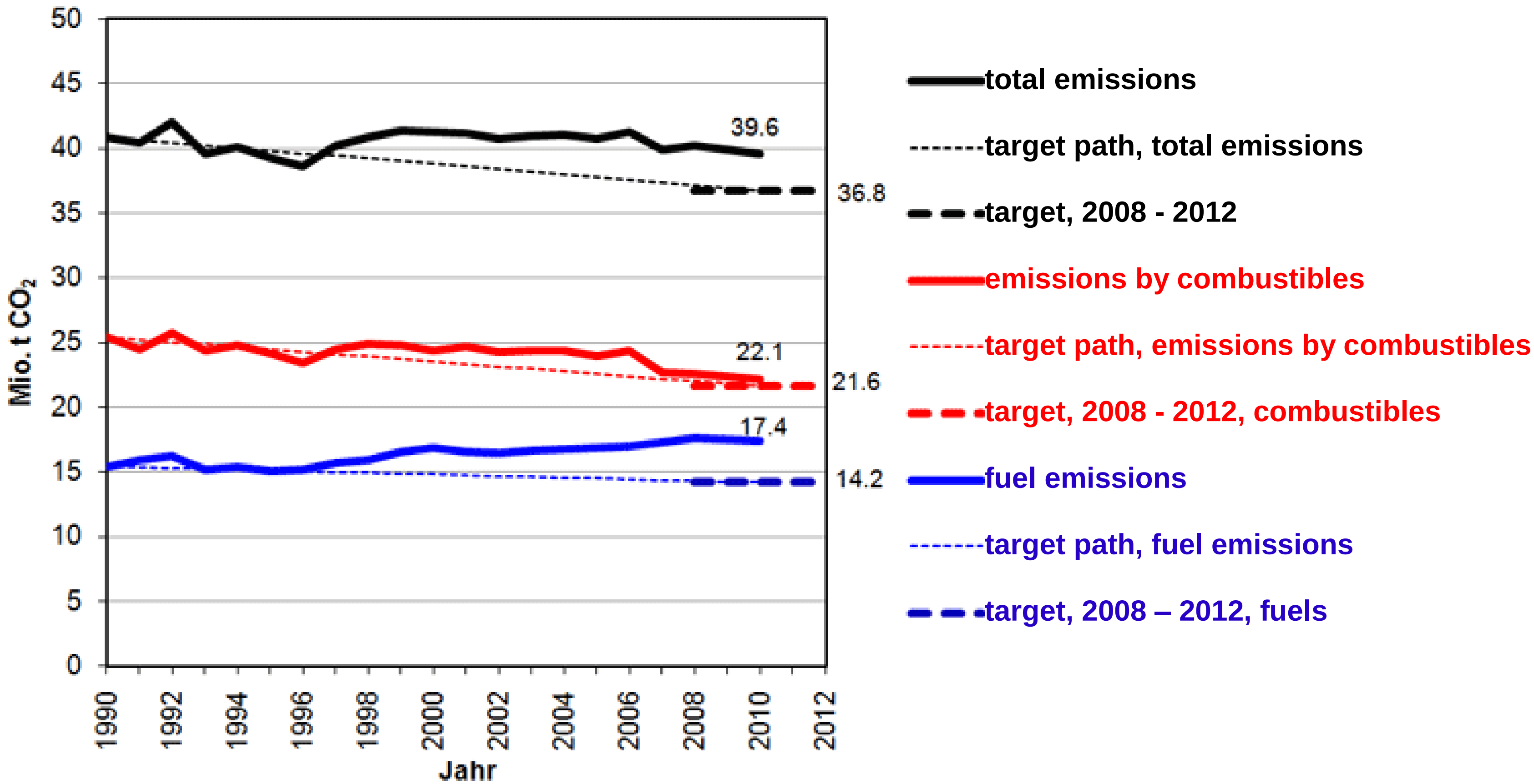


Fig. 1: Trajectories of carbon dioxide emissions in Switzerland (source: Bafu)

2. Trends in the Private Transportation Sector since 1970

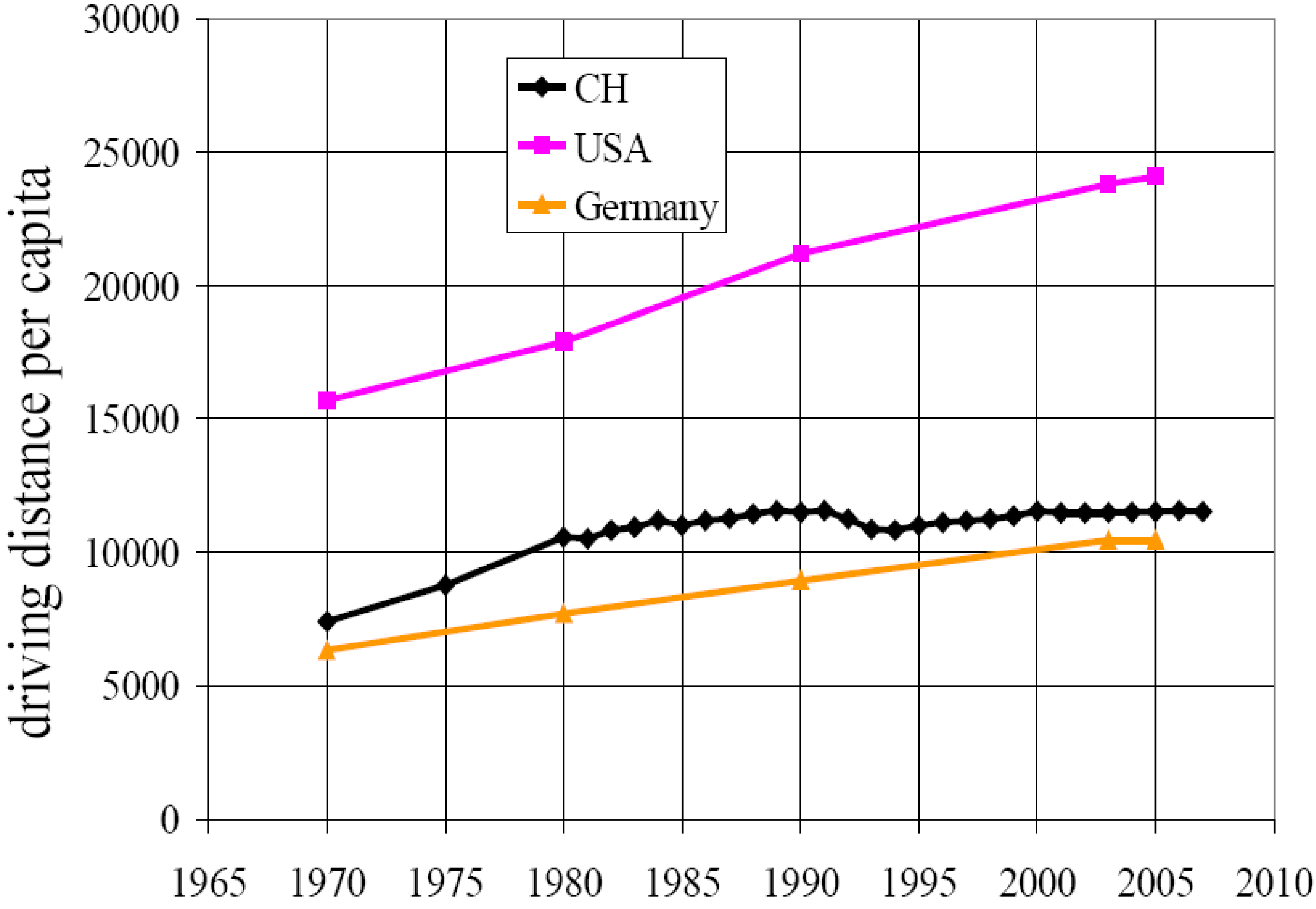


Fig. 2: Trajectories of the total annual cars driving distance per capita

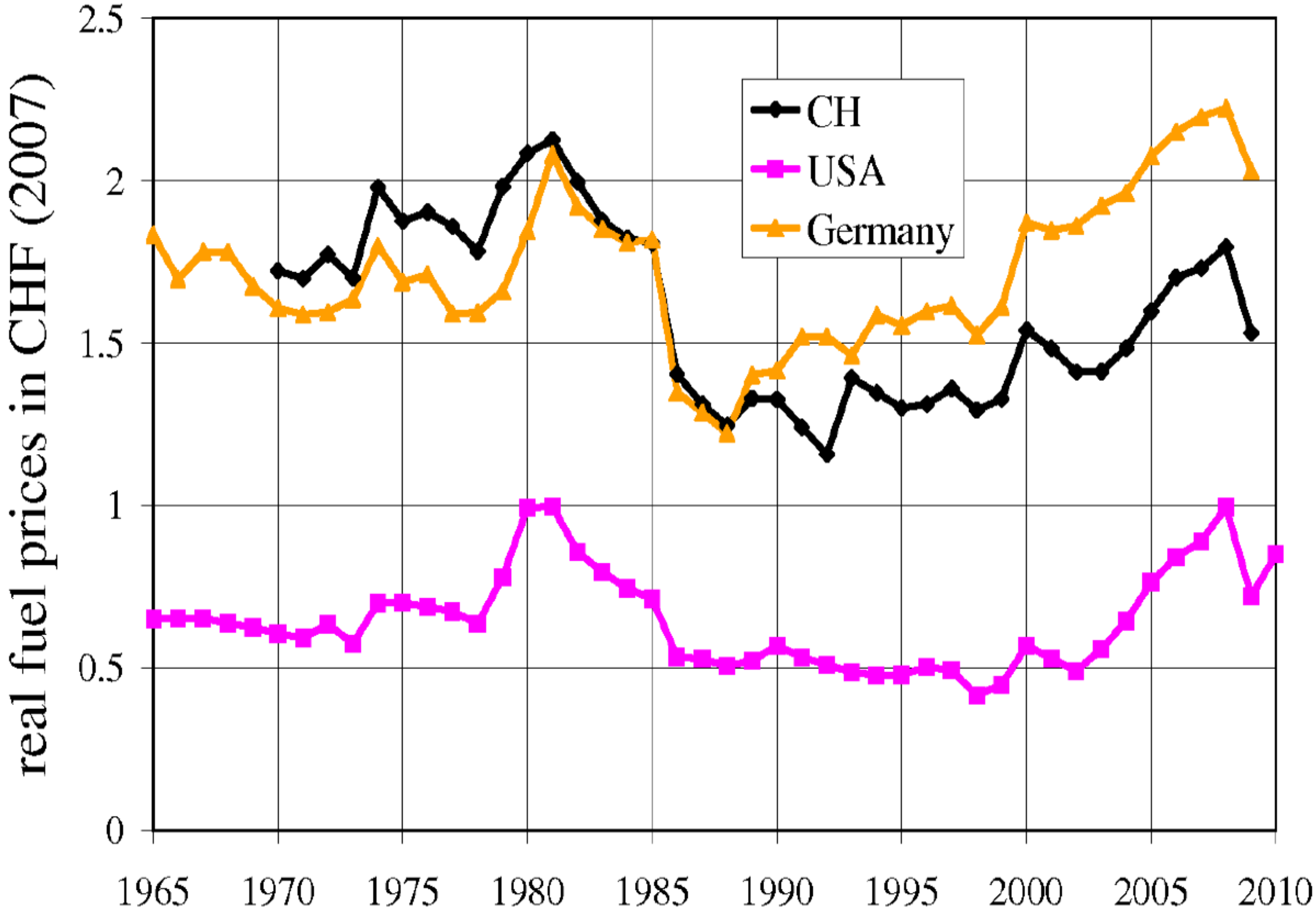


Fig. 3: Trajectories of the real fuel prices

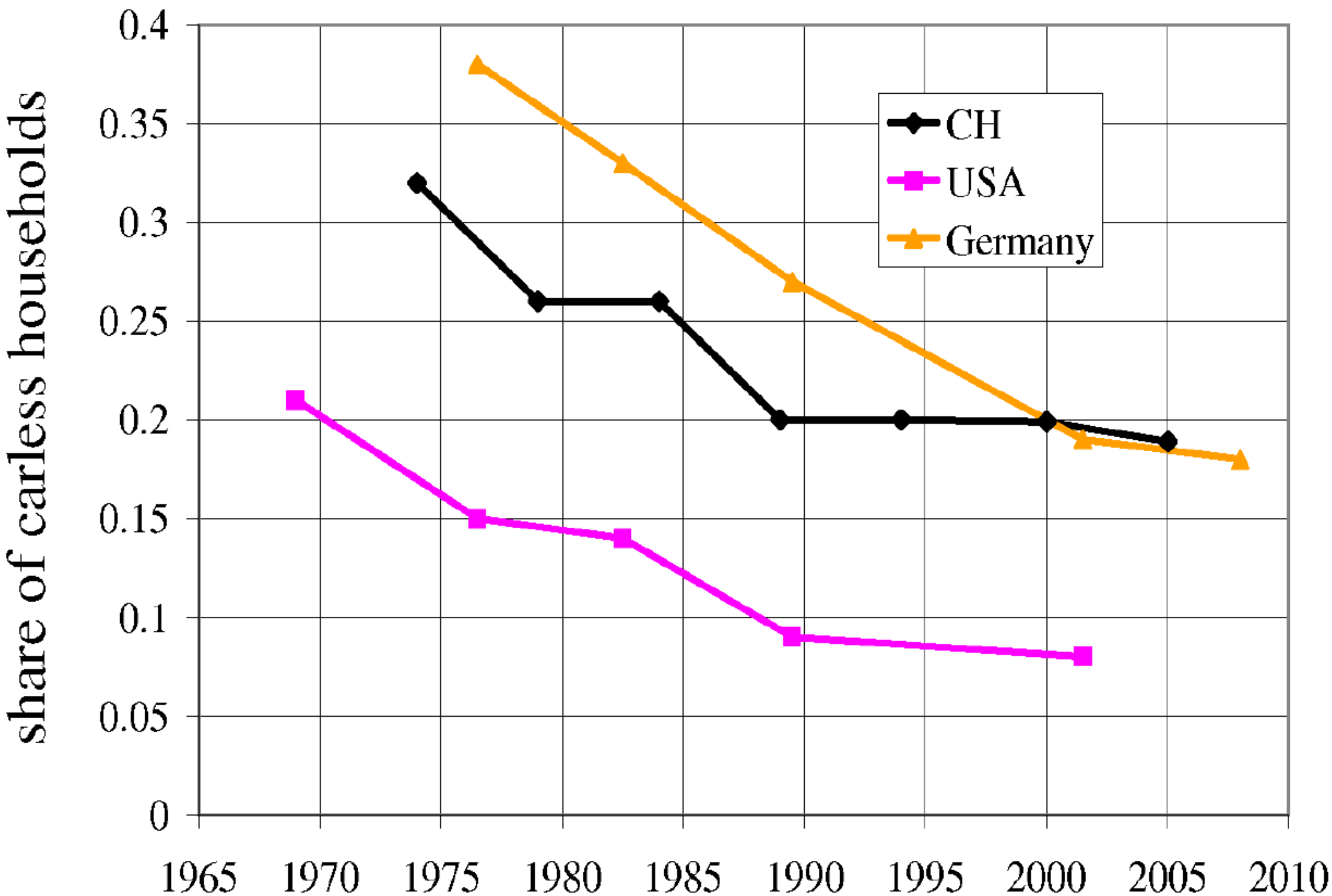


Fig. 4: Trajectories of the shares of carless households (CH/GER/USA)

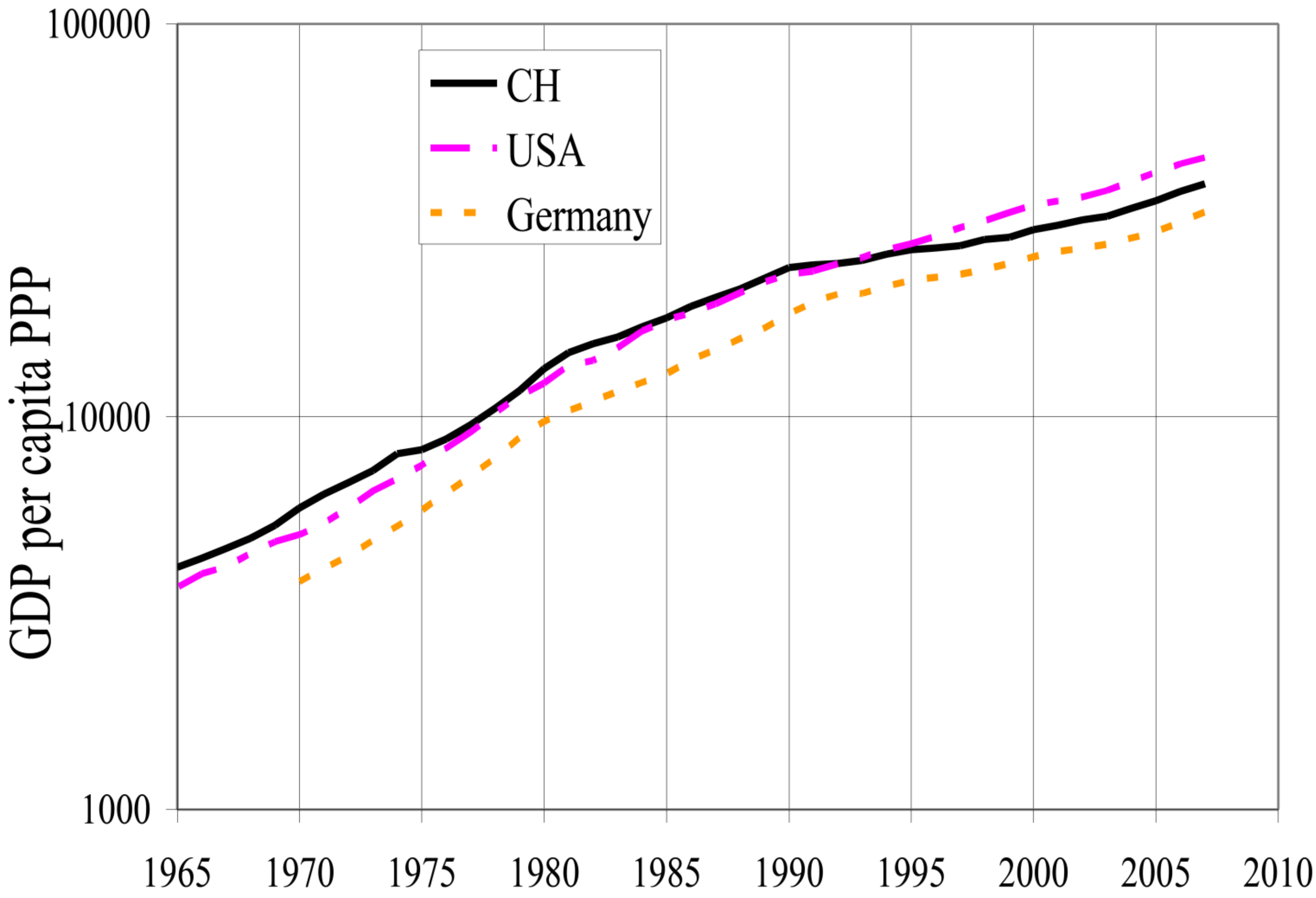


Fig. 5: Gross domestic product, measured in purchasing power parity (PPP).

Findings

- Co-movements between car-km per capita and the share of carless households
- This co-movement does not seem to be driven by fuel prices alone, but possibly also by the offer of public transportation (see differences between CH and GER)
- The share of carless households is rather high in CH and GER and should therefore be captured in a model
- The share of carless households is very low in the USA and does not need to be captured
- The reason for the low share of carless households in the USA may be both the low price of fuel and the rather small offer of public transportation

3. Model requirements and data choice

- A “good” model used for forecasting aggregate driving demand **should capture the share of carless households**. (Except countries with a very low share of carless households, e.g. USA and Australia)

- **Swiss data** is chosen, because
  - There exists a high share of carless households, despite of the high income per capita
  - There exist datasets with vast amounts of information at the household level
  - Comparable data exist for every 5 years
    - Swiss Federal Statistical Office
    - Data on about 27’000 households
    - Very detailed information on households (place of living (x/y), income, vast number of socioeconomic variables, …)

  - There exist great differences in offer of public transportation across the regions

4. Existing modelling approaches

4.1 Macroeconomic approaches

- Data: Macroeconomic time-series data
- Examples: Total fuel consumptions, income (gdp), fuel price, ...

4.2 Microeconomic approaches

- Data: Data on household level
- **"Families"**

  i. **Discrete-Choice Models:**
  ("what car-type does a household choose?")
  Problem: *Only* car-type, without annual mileage

  ii. **Demand** (annual mileage or fuel demand), given a household owns a car (OLS, etc.)
  Problem: Interaction between the car-type choice and the annual mileage

  iii. **Tobit Model** (car y/n, car-km)
  Problem: Fixed costs cannot be mapped

  iv. **Discrete-Continuous Choice Models:**
  Step 1: Choose a car-type
  Step 2: Choose the annual mileage
  Problem: Works only if 1 household = 1 car

  v. ***Multiple* Discrete-Continuous Choice Models**
  Problem: Fixed costs are not included

5. The extended Multiple Discrete-Continuous Choice Model

- This model overcomes the problems of the models mentioned above (4.2)

- This model is based on a microeconomic model

  Direct utility function

  Budget restriction

  ==> Marshallian demand function of car-km

- Aim

  - *Forecasting the* ***average annual mileage*** *and the* ***share of carless households***

    ... conditional on different economic circumstances

Basic idea of the model (I) : Assumption on the household's behaviour

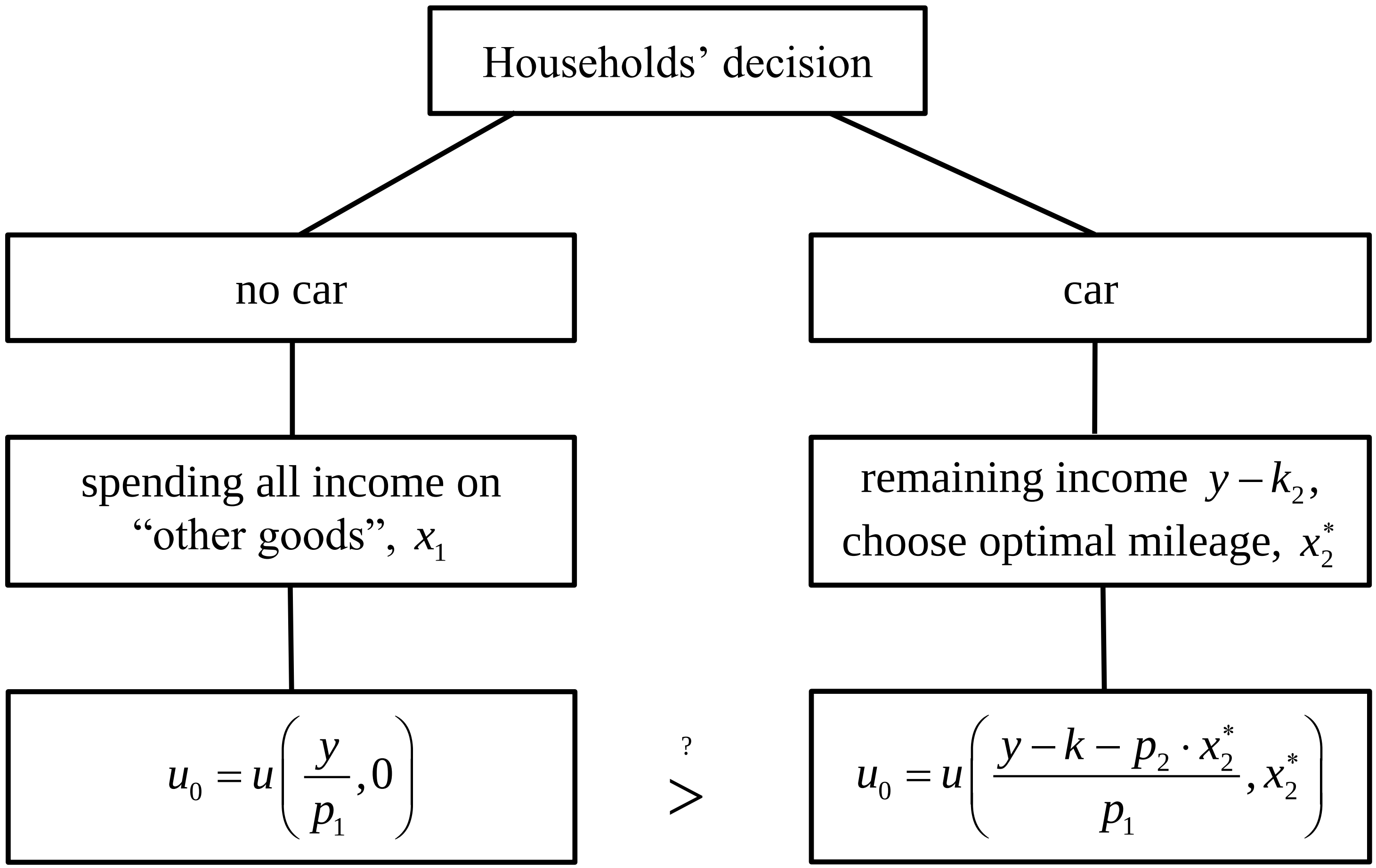


Fig. 6: Optimal decision of a household with a *low* preference for car driving

Basic idea of the model (II) :

x_2 :   Car – km

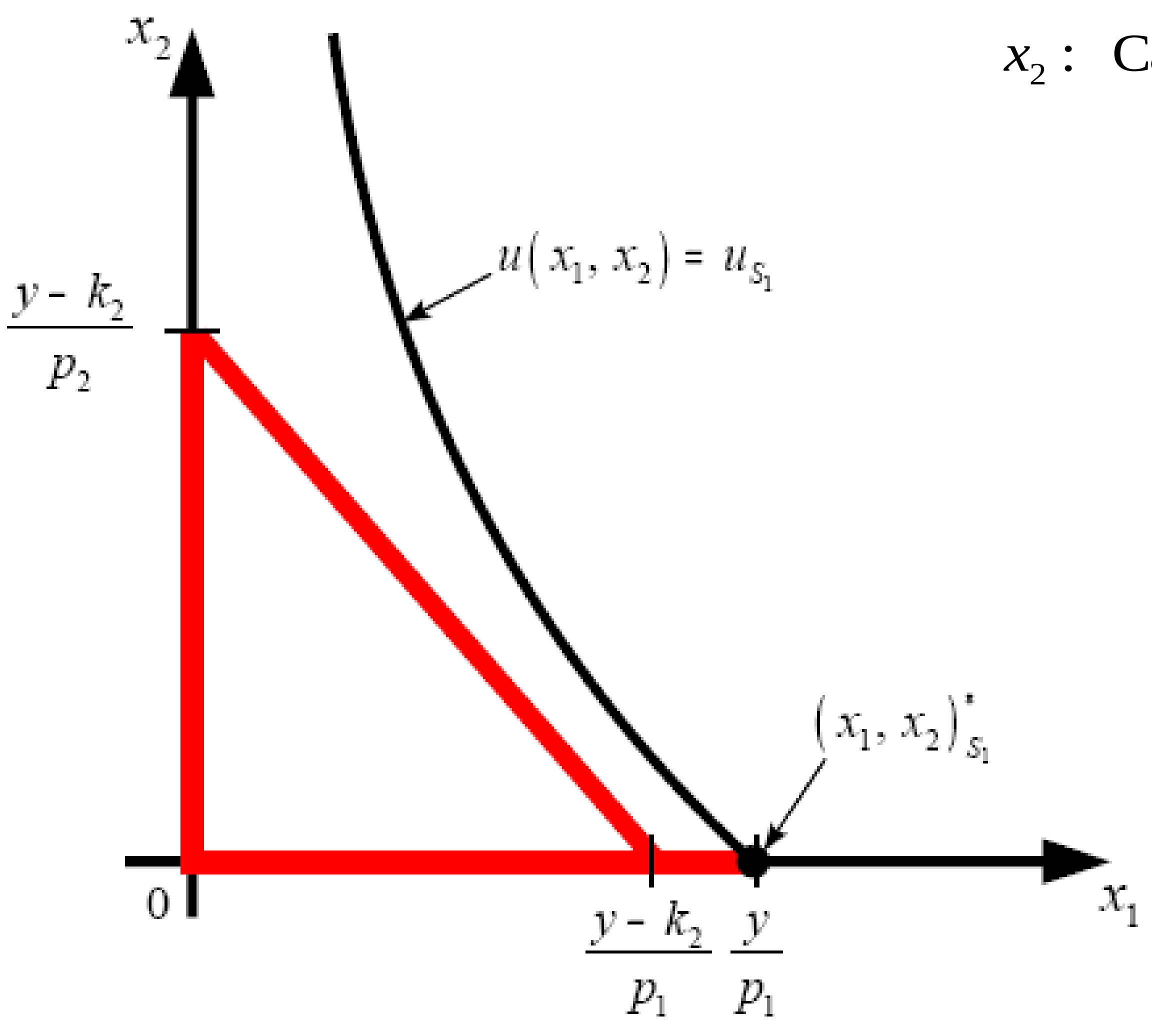


Fig. 7: Optimal decision of a household with a *low* preference for car driving

Basic idea of the model (III)

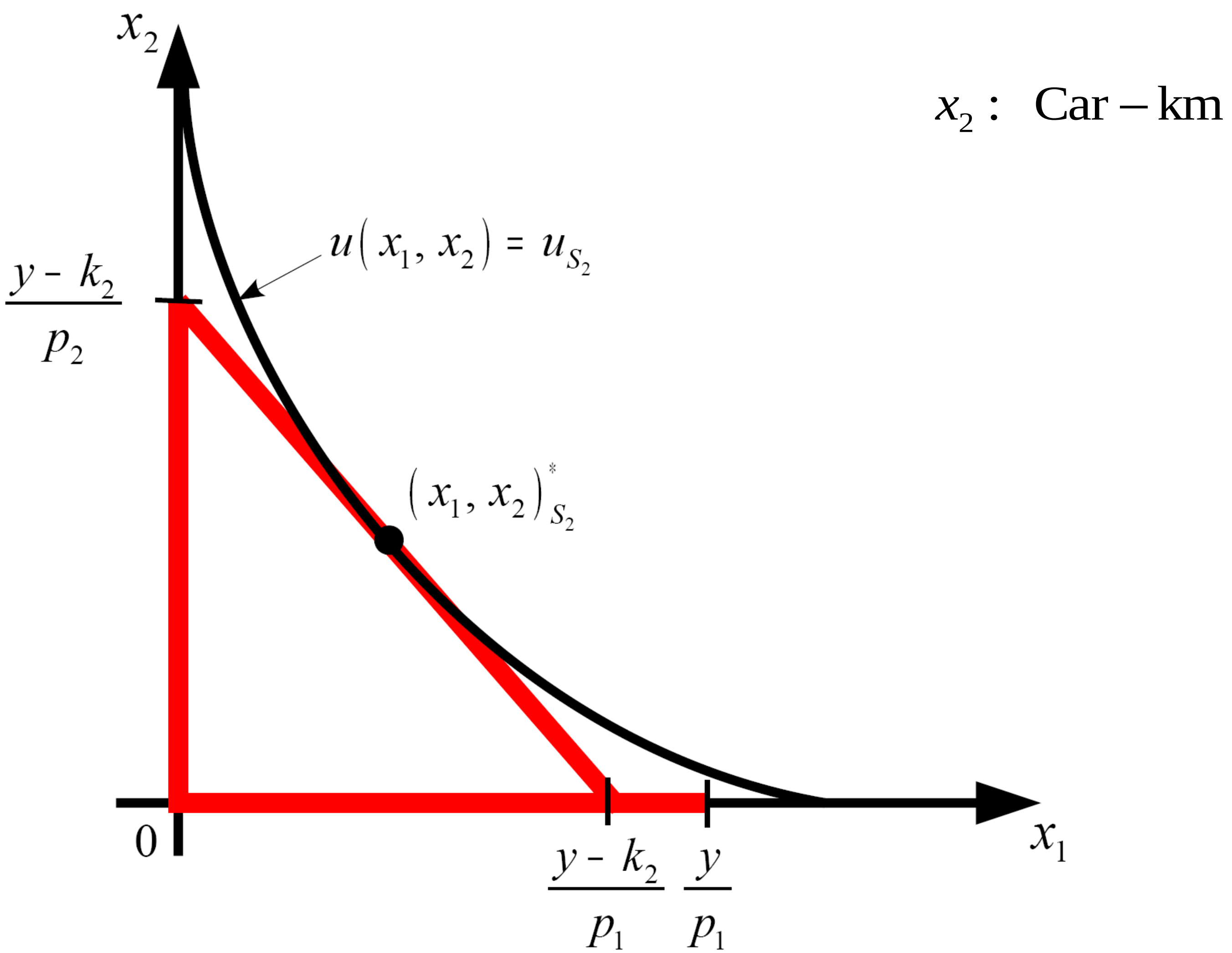


Fig. 8: Optimal decision of a household with a *high* preference for car driving

Basic idea of the model (IV)

- The researcher does not exactly know the households‘ utility function
- The households’ utility function contains stochastic parameters
- The Marshallian demand is stochastic ("density function")
- The density function of the Marshallian demand function will be adapted to the observed data by choosing the appropriate parameters

- Density function and observed data

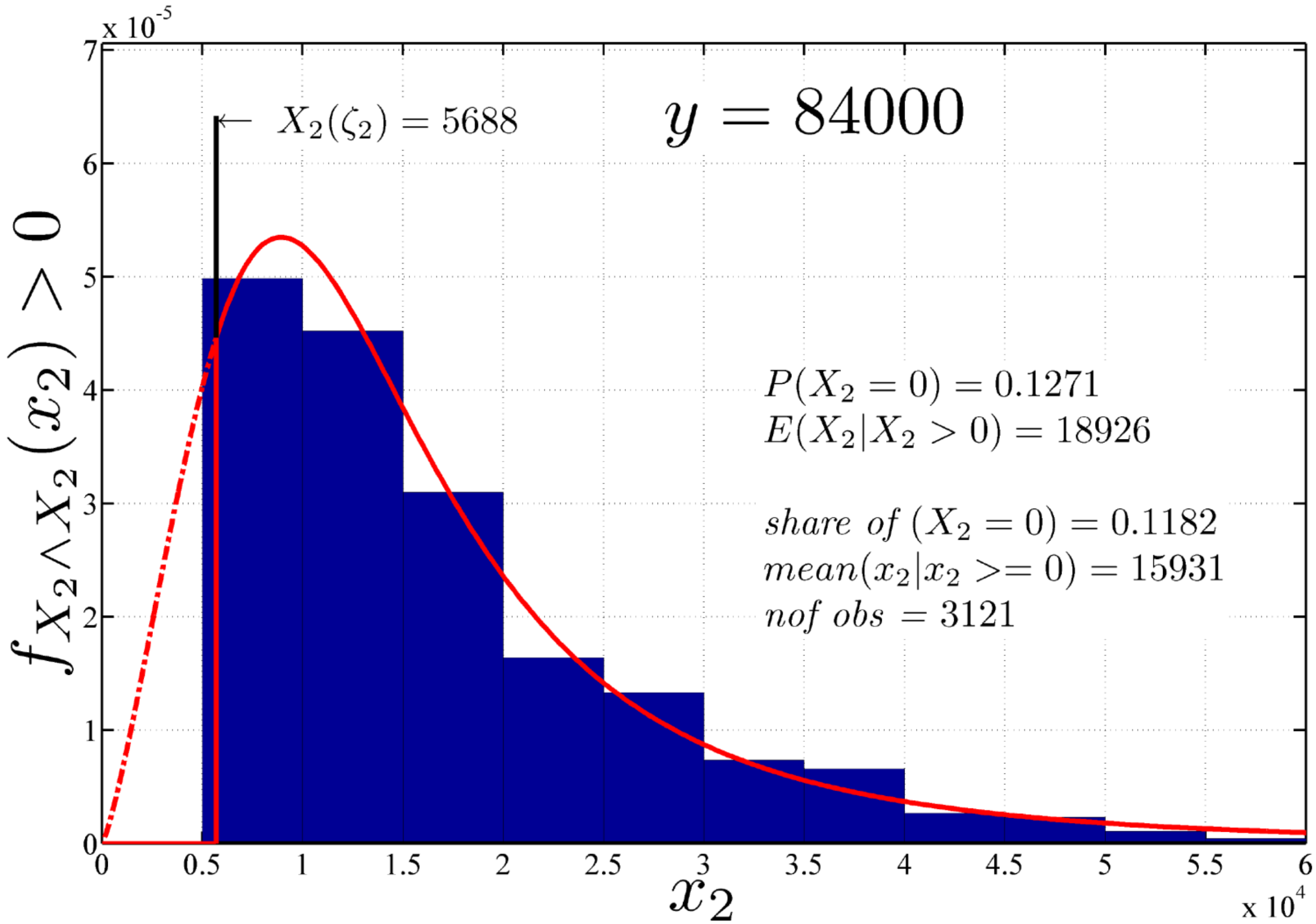


Fig. 9: Histogram and density function, household income 84'000 CHF.

- Choice of a specific **utility function** and specific assumptions on the **distribution of the stochastic parameter** lead to a fast **computation of the parameters** (Maximum Likelihood)

$$\max_{x_1, x_2, x_3, \ldots} u(x_1, x_2) = (x_1 + a_1)^d + \exp(m + \beta \cdot \zeta) \cdot (x_2 + a_2)^d$$

Subject to: $y = I(x_2 > 0) \cdot k_2 + p_1 \cdot x_1 + p_2 \cdot x_2$

k_2:	Fixed costs of the car
x_2:	Car-km
x_1:	All other goods (housing, holidays, consumption goods,…)
p_2:	Marginal costs of a car-km (Note: $p_1 = 1$)
$m + \beta \cdot \zeta$:	Relative preference for driving a car
$\beta \cdot \zeta$:	Stochastic component of the relative preference for driving a car
ζ:	Standard-Gumbel distributed

Example: $m = \gamma_0 + \gamma_1 \cdot rural$, where $rural = 1$, if the household lives in a rural area

$\gamma_0,\ \gamma_1,\ a_1,\ a_2, \beta, d$: Parameters (to be determined)

- Utility function: The role of parameter a_2

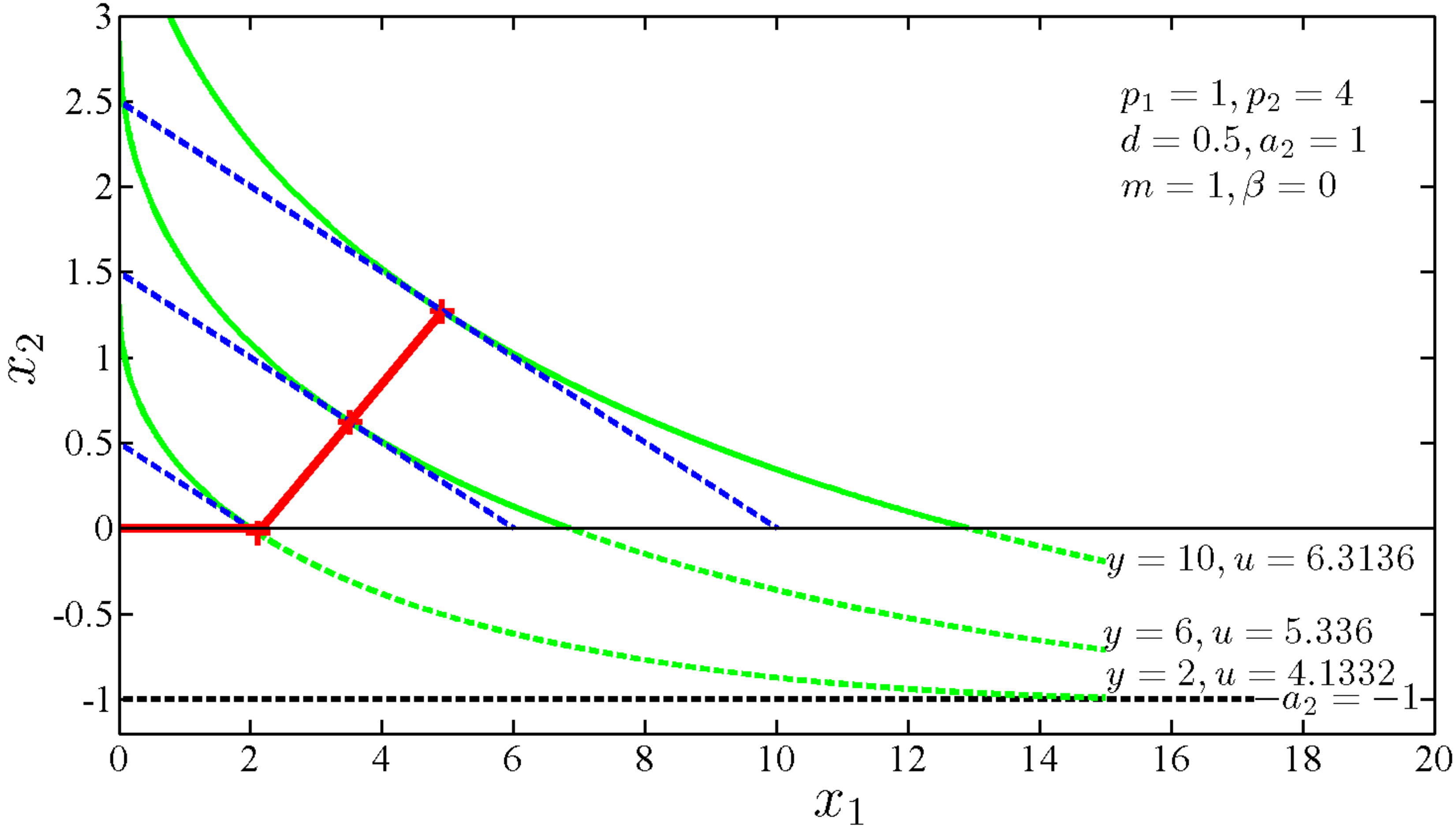


Fig. 10: Indifference curves of the utility function, the role of parameter a_2

- Utility function: The role of parameter *d* (smaller value of *d*)

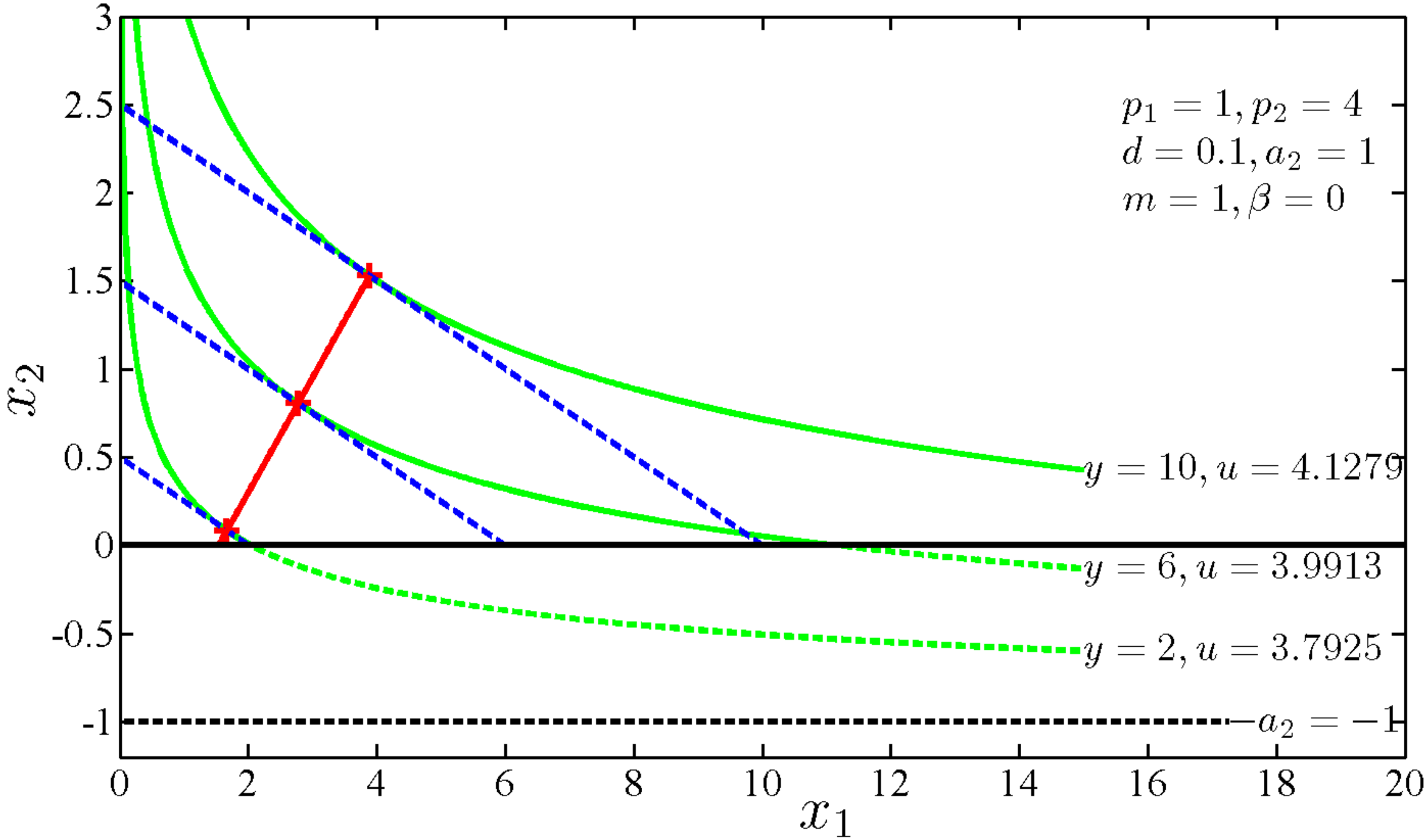


Fig. 11: Indifference curves of the utility function, the role of parameter *d*

- Density function of driving demand x_2: The effect of a change of parameter *d*

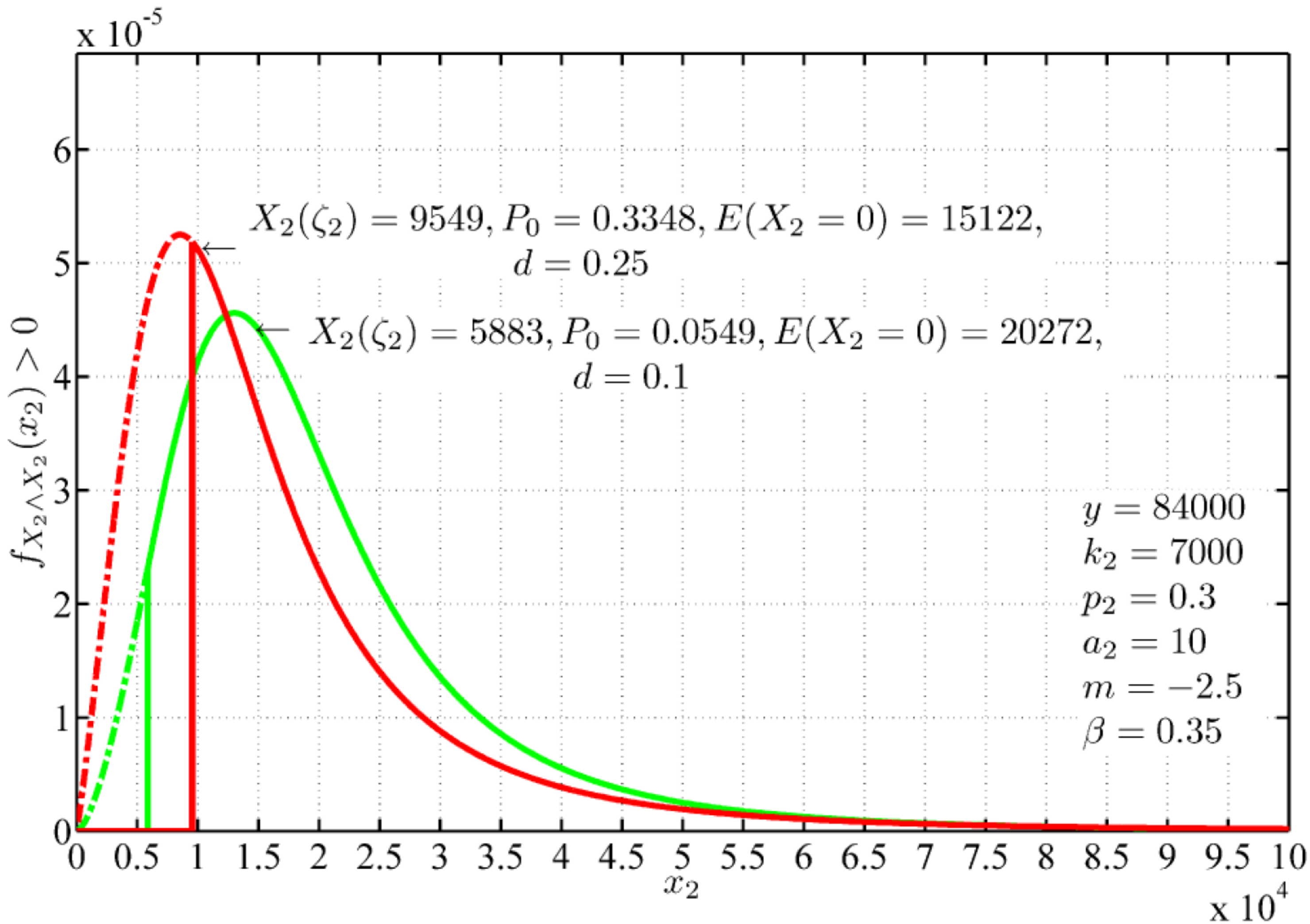


Fig. 12: Indifference curves of the utility function, the role of parameter *d*

- Density function of driving demand x_2: The effect of an increase in driving costs p_2

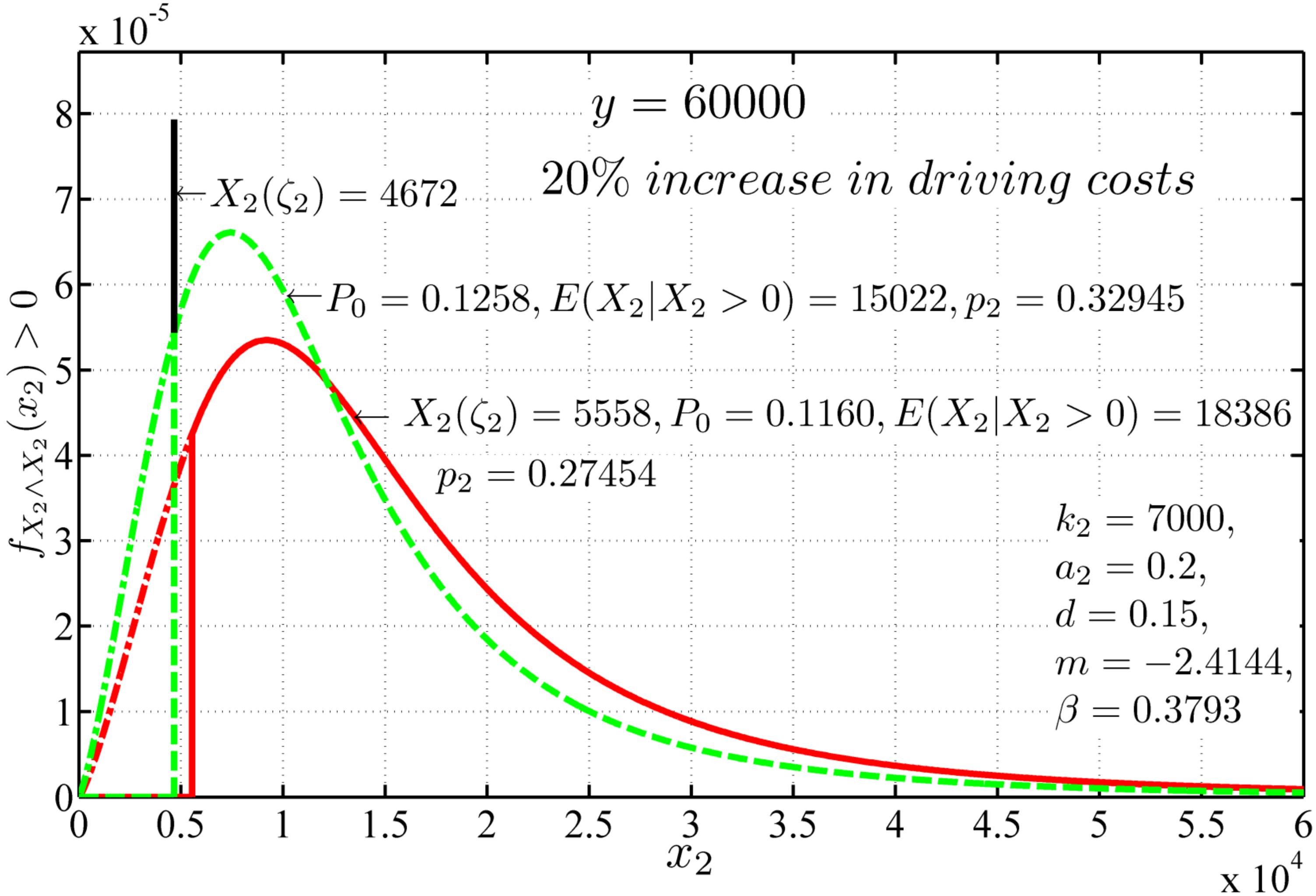


Fig. 13: Density function for different driving costs p_2, household income 60'000 CHF.

- Density function of driving demand x_2: The effect of an increase in fixed costs k_2

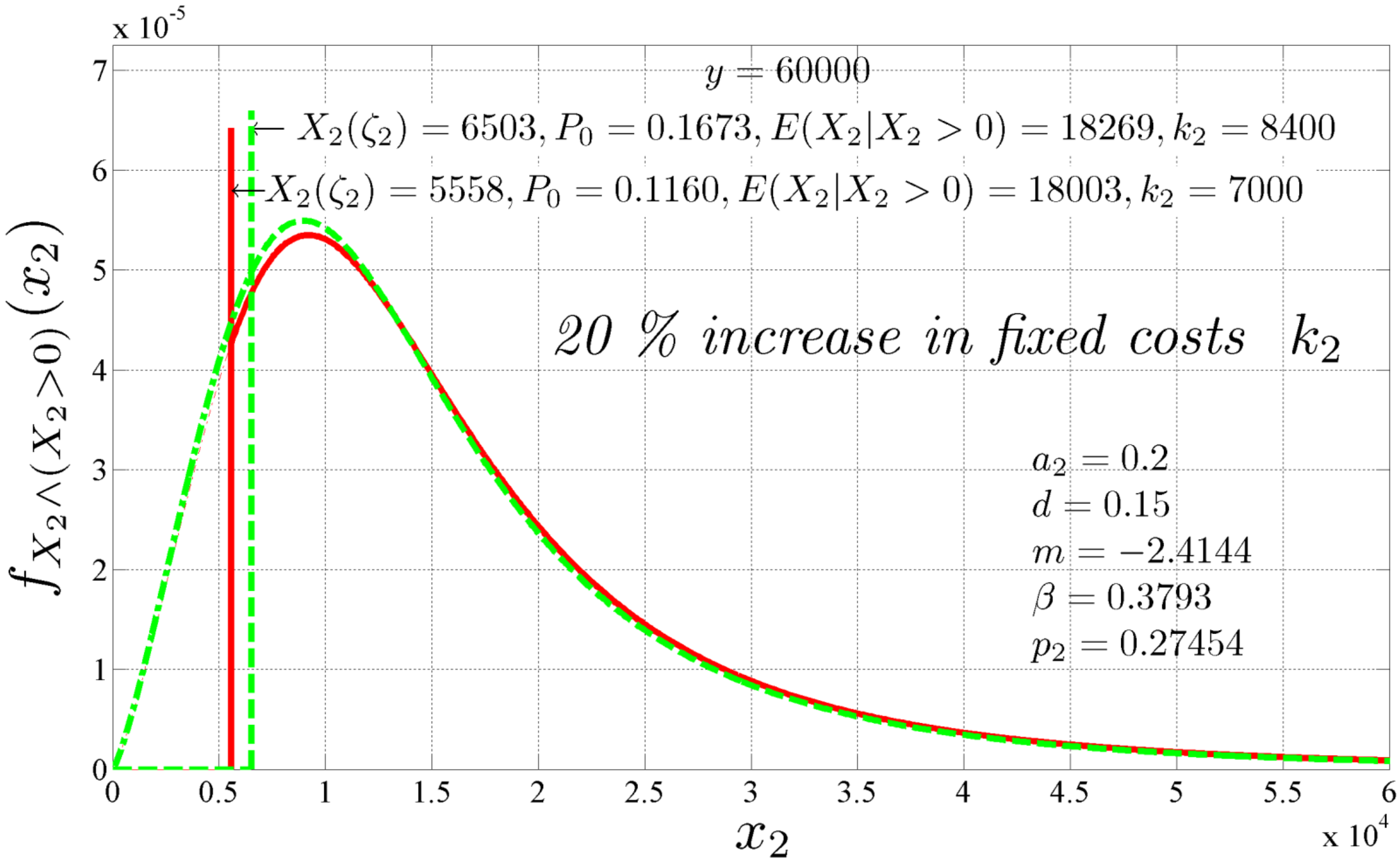


Fig. 14: Density function for different fixed costs k_2, household income 60'000 CHF.

6. Results based on the extended Multiple Discrete-Continuous Choice Model

Main results

- *Elasticity of car-km with respect to fuel prices*: -0.25
- *Elasticity of fuel demand with respect to fuel prices*: -0.31*
- The effect of a **tax on car ownership** on car-km is **four times lower** than the effect of a **fuel-tax,** *per amount of tax revenue*
- If a household moves from an urban to a rural area: +47% more car-km
- *Elasticity of car-km with respect to the households' income*: 0.82
  … thus given the preferences for car driving remain unchanged, the fuel prices should grow more than three faster than the households' income, when the car-km per capita should be constant
- Results based on this model using Swiss data suggest that the preferences for car driving of Swiss households decrease over time (see "further results (v)")

* This result yields by using the relation between fuel prices and the households' choice of the cars' fuel efficiency. This relation was computed by use of the Dataset of Erath and Axhausen (2010).

Further results (i): *Non-marginal effects*

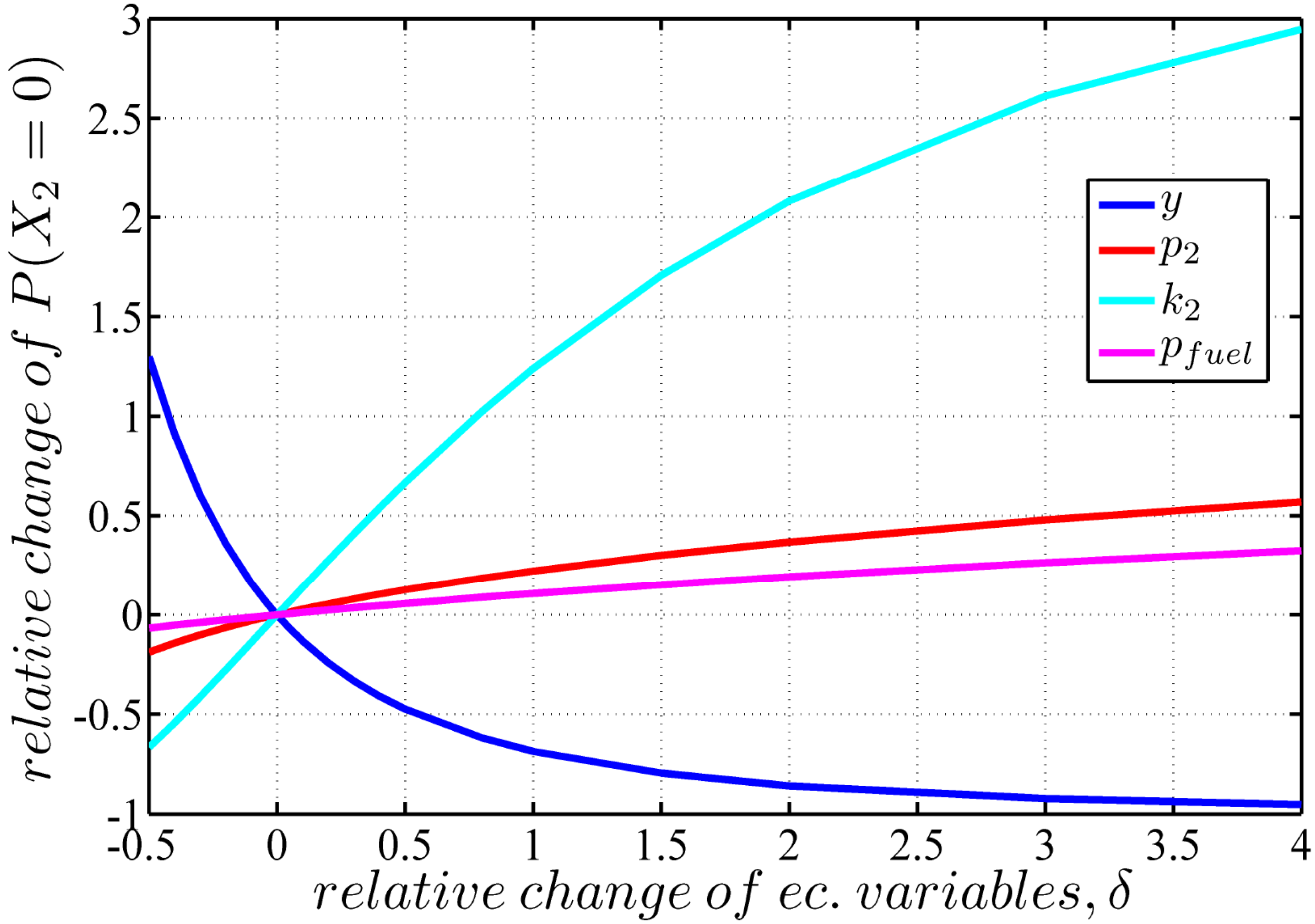


Fig. 15: Effects of different economic variables on the share of carless

Further results (ii): *Compensation needed for keeping utility constant when fuel prices increase (≈WTP for fuel efficiency)*

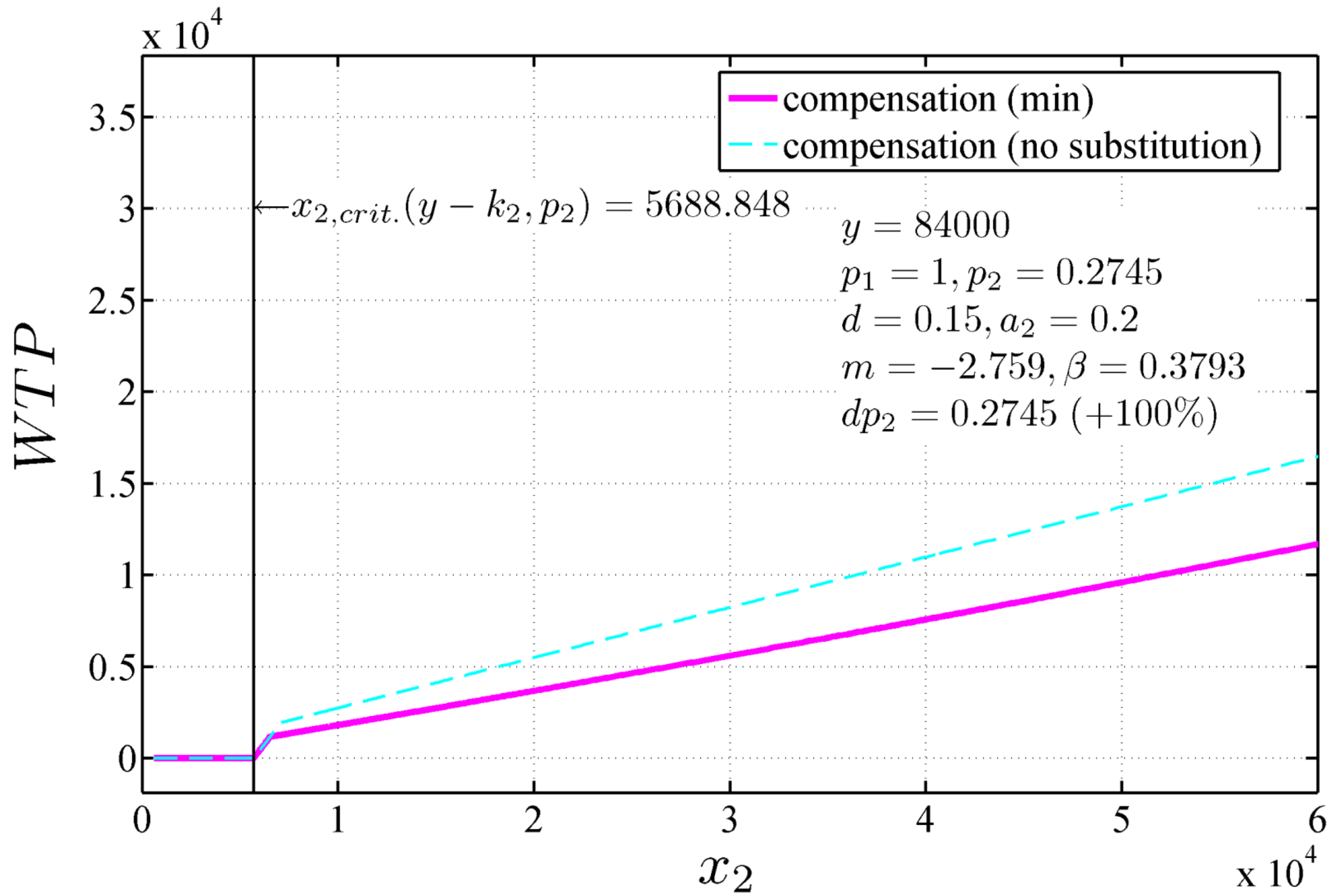


Fig. 16: Compensation needed for keeping utility constant (fuel price increase)

Further results (iii): *Compensation needed for keeping utility constant when fixed costs increase (≈WTP for car ownership*

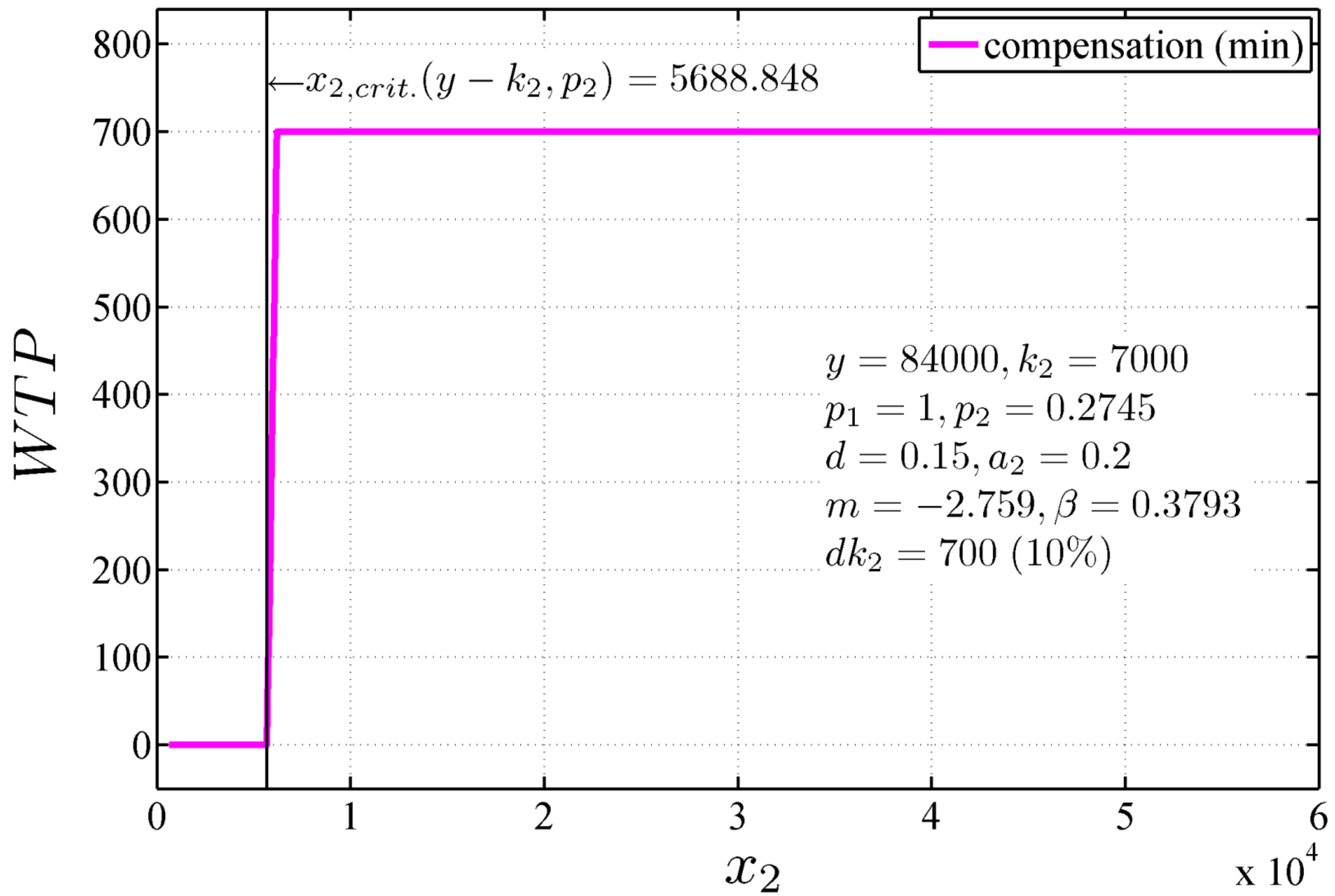
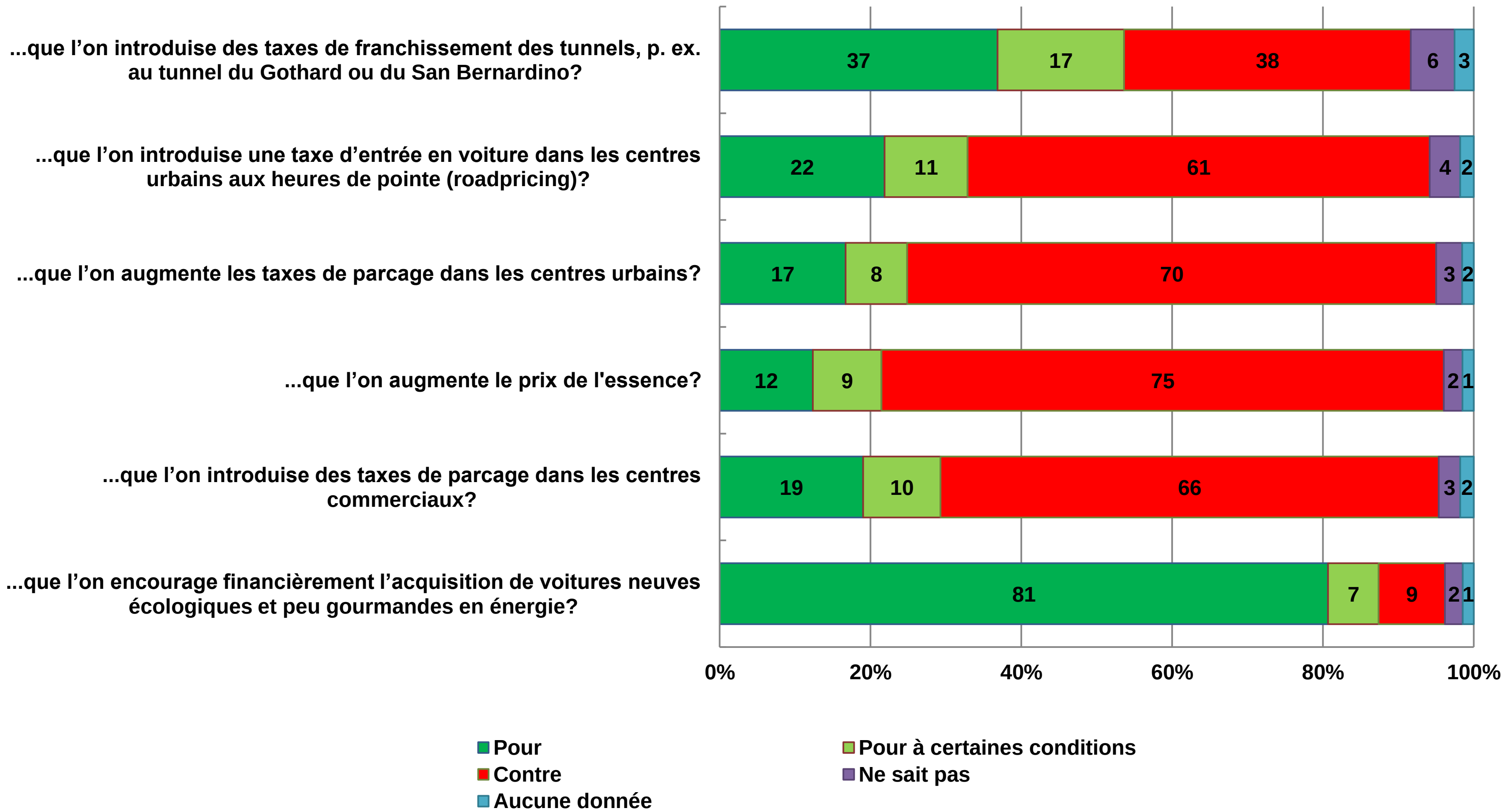


Fig. 17: Compensation needed for keeping utility constant (fuel price increase)

Further results (vi): *Household's preference for an increase in fuel prices*



Source: swiss federal office of statistics, micro census on travelling behaviour 2010.

Fig. 19: Household's preference for an increase in fuel prices

Further results (v): Dataset 2000 vs. 2005

- Calibrating the model by use of the micro census data 2000 and forecasting the car-km in 2005 using the 2005 data yields a too high value
- …could be due to a change in the households' preferences
- … households' preferences could change because of changes in the public transportation sector or due to an increase in traffic congestion

- Private versus public transportation (i): Speed

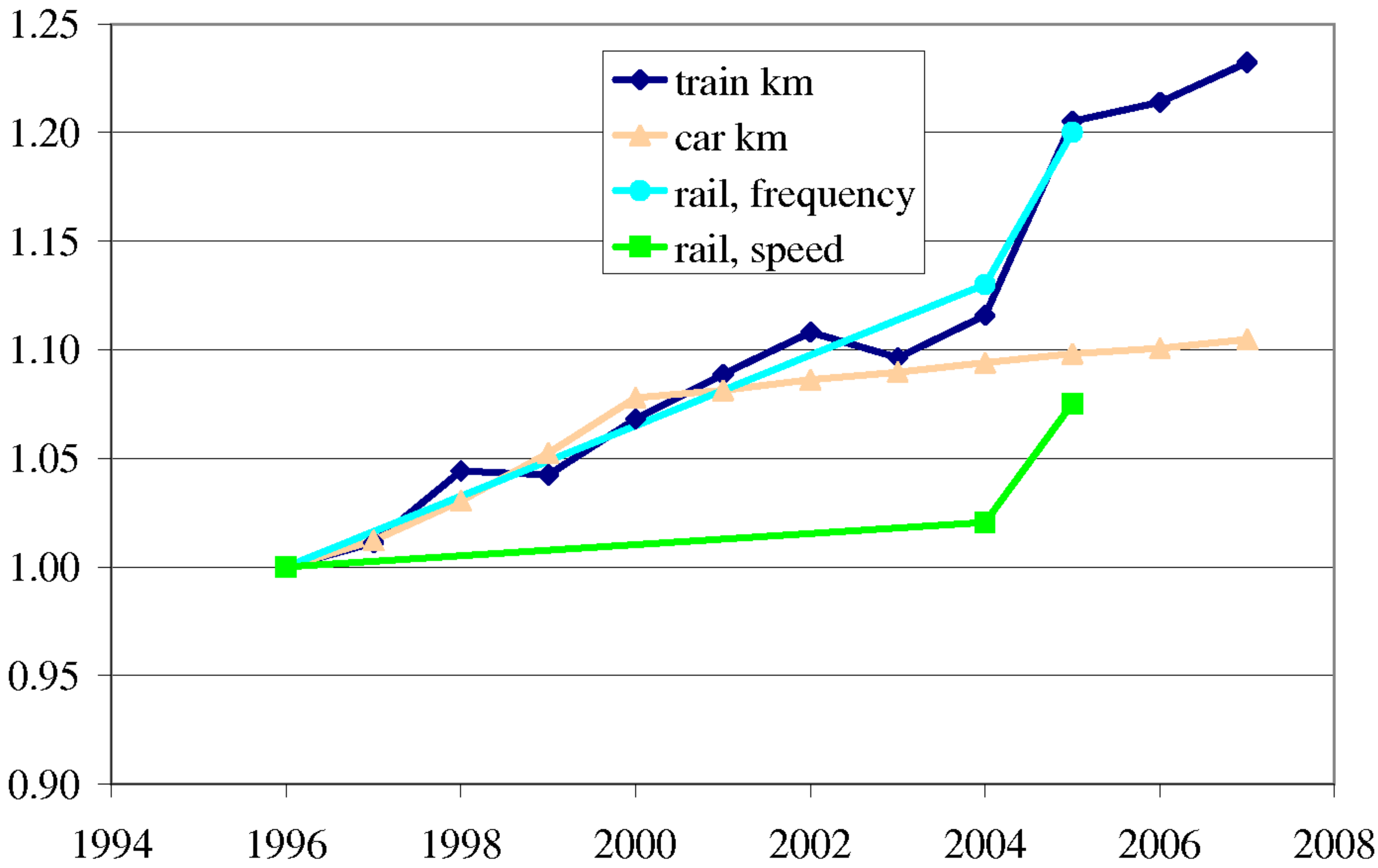
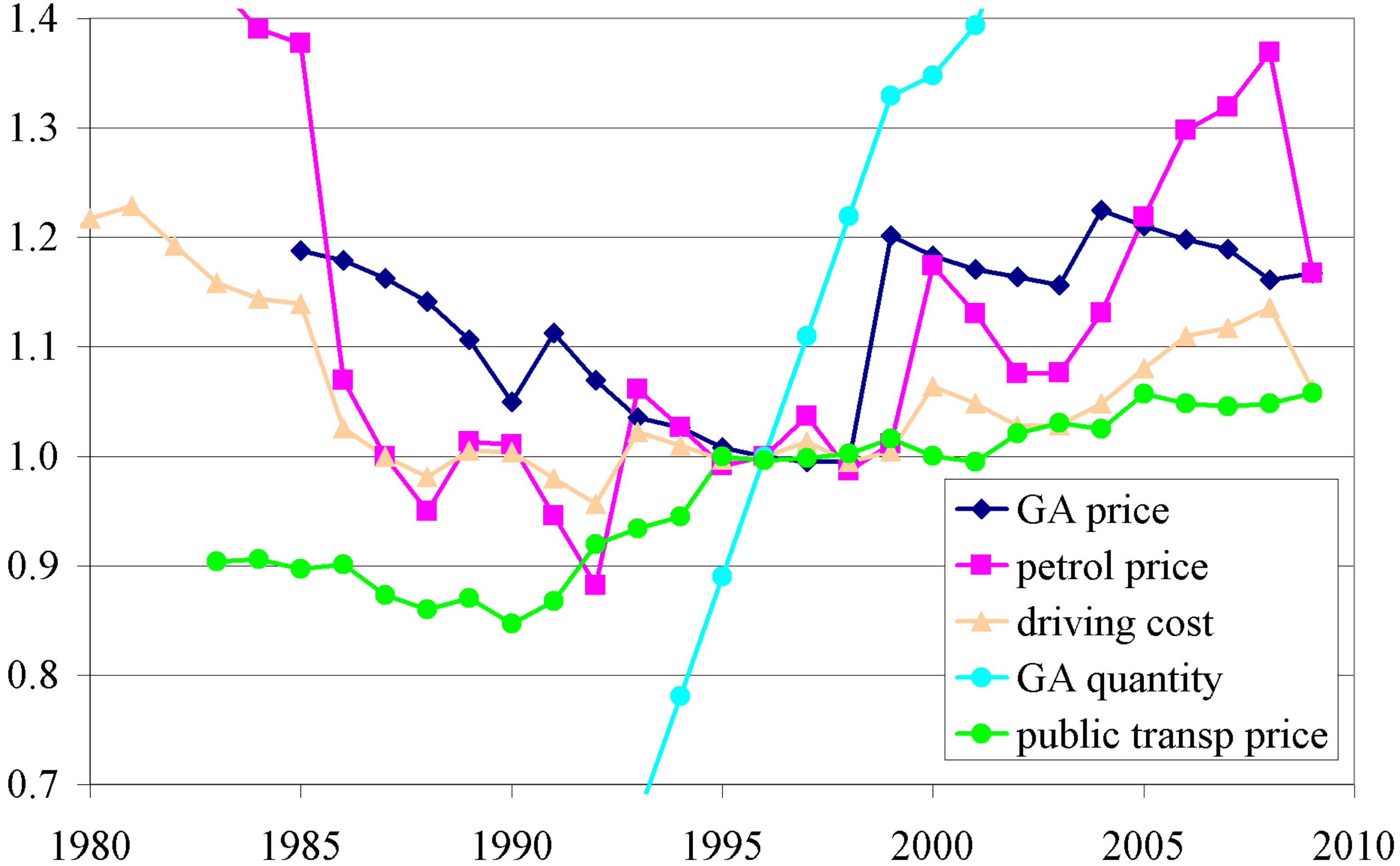


Fig. 20: Increase in frequency and speed of Swiss Federal Railways trains

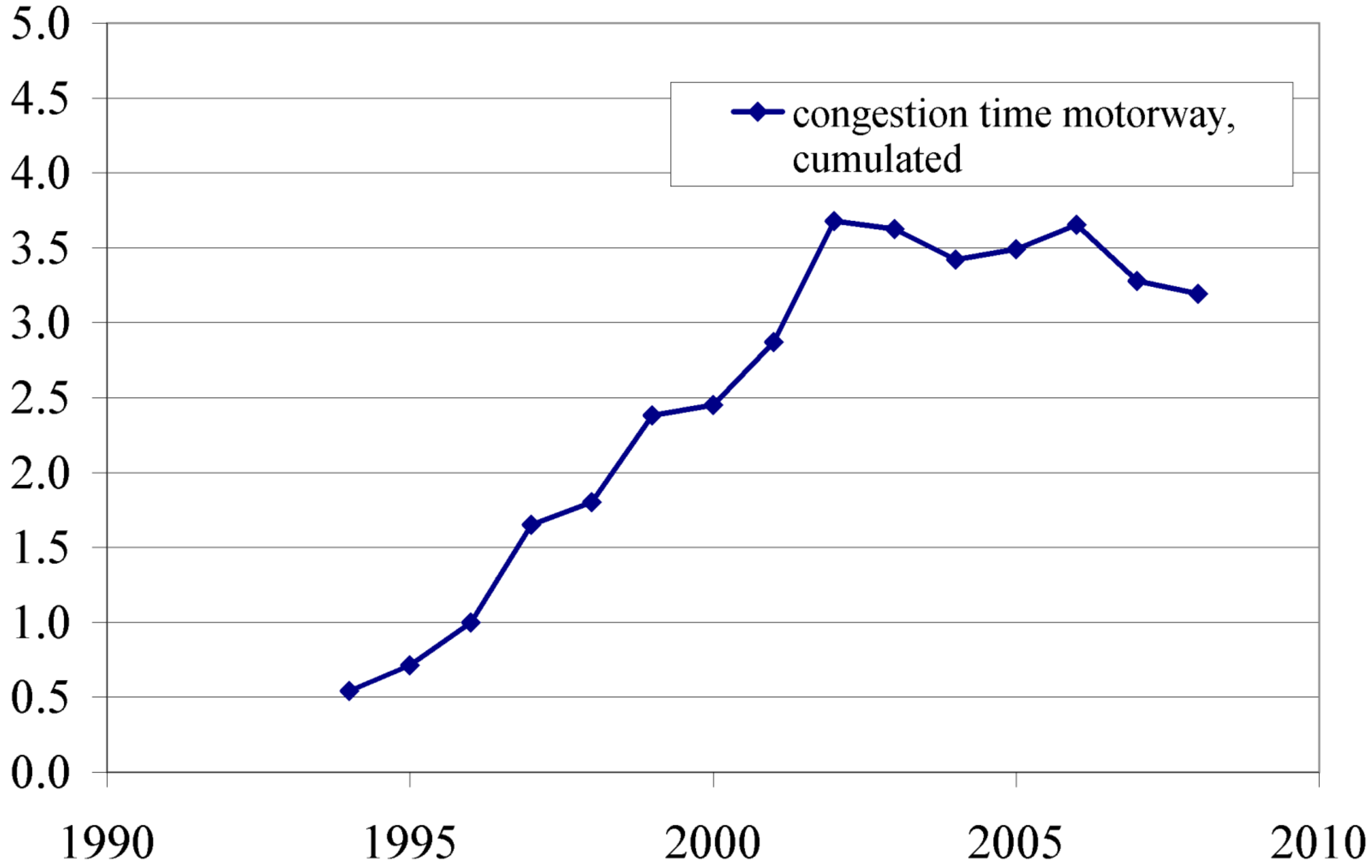
- Private versus public transportation (ii) : Costs



Note: All values are normalized to one (1996)

Fig. 21: Real prices of public transport and demand for flat rate tickets (GA)

- Private versus public transportation (iii) : Trafic congestion



Note: All values are normalized to one (1996)

Fig. 22: Congestion time on Swiss motorways Private versus public transportation

- Private versus public transportation (iv) : Share of passenger km

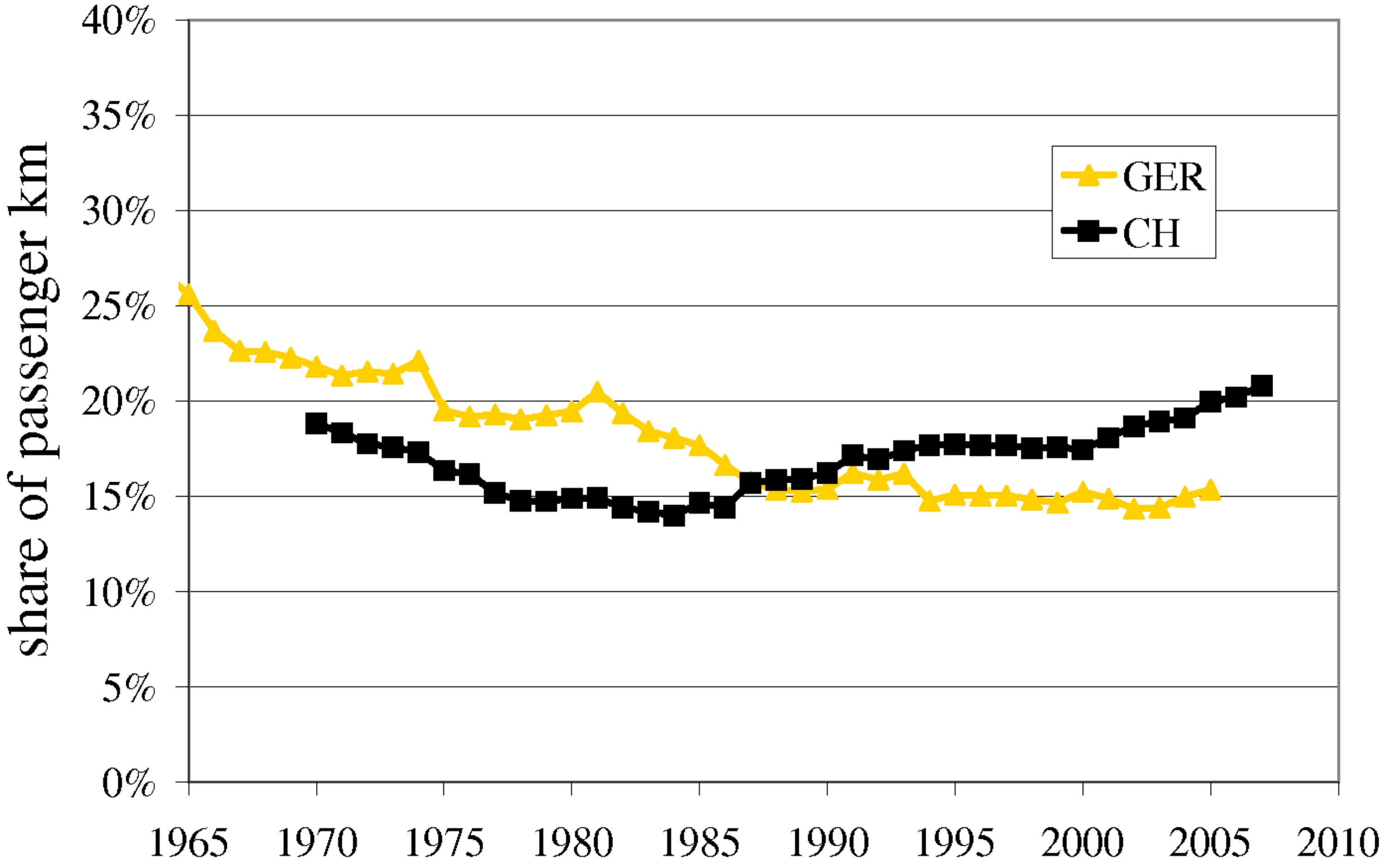


Fig. 23: Passenger kilometres as a percentage of the total road and rail distances covered using public transport.

7. Further applications of the Multiple Discrete-Continuous Choice Model

All **consumer goods with a fixed cost component**, e.g.

- Printer (yes/no/type), how many pages
- Mobile phone subscription fees (yes/no/type), how many minutes connection
- Health insurance (yes/no/type), how many services consumed
- Skiing equipment (yes/no/type), how many days skiing
- etc.

Supplementary information

(I) Price elasticities by different model types

(II) Density function of the modified Multiple Discrete-Continuous Model

(III) OLS Method: Bias

(IV) Overview of model types

(V) Effects of different economic variables on the share of carless households

(VI) Renominated researchers

(I) Price elasticities by different model types

Type of model	MDCEV	MDCEV	MDCEV 60,000km	Tobit	MDCEV 60,000km	Tobit	Probit
Dataset	mz05	mz05	mz05	mz05	Erath	Erath	Erath
Fixed costs	no	yes	yes	--	yes	--	--
$\varepsilon_{E(X_2),p_2}$	-1.36	-1.19	-0.68	--	-0.69	-0.379 (0.02036)	--
$\varepsilon_{E(X_2),p_{fuel}}$	-0.564	-0.492	-0.28	--	-0.252 {-0.268}	-0.171 (0.01243)	--
$\varepsilon_{E(X_2),y}$	1.349	1.189	0.77	0.616 (0.0106)	0.822 {0.829}	0.786 (0.05809)	--
$\varepsilon_{E(X_2),k_2}$	--	-0.180	-0.17	--	-0.15	--	--
$\varepsilon_{P(X_2=0),p_2}$	1.63	0.297	0.26	--	0.21	0.472 (0.03908)	--
$\varepsilon_{P(X_2=0),p_{fuel}}$	0.682	0.124	0.11	--	0.0748 {0.093}	0.290 (0.0239)	0.2374 (0.072)
$\varepsilon_{P(X_2=0),y}$	-1.618	-1.437	-1.41	-0.850 (0.019)	-1.3	-0.950 (0.1109)	-1.248 (0.035)
$\varepsilon_{P(X_2=0),k_2}$	--	1.390	1.31	--	1.09	--	--
$\varepsilon_{x_{fuel},p_{fuel}}$	--	--	--	--	-0.31	--	--
$\varepsilon_{x_{fuel},y}$	--	--	--	--	0.978	--	--
Source:	Table A3.11.4	Table A3.11.4	Table A3.15.1	Table A3.15.1	Appendix A3.14	Appendix A3.14	Appendix A3.14

Table 1: Price elasticities of different model types and different data

(II) Density function of the modified Multiple Discrete-Continuous Model

$$f_{X_2 \wedge (X_2>0)}\left(z \mid \theta, p_1, p_2, y, s\right) = f_\varsigma\left(V_1 - V_2\right) \cdot \left(\frac{1-d}{\frac{y - p_2 z}{p_1} + a_1} \cdot \frac{p_2}{p_1} + \frac{1-d}{z + a_2} \right),$$

$$P\left(X_2 = 0 \mid \theta, p_1, p_2, y, s\right) = P\left(\varsigma < V_1 - V_2\right) = F_\varsigma\left(V_1 - V_2\right)$$

with

$$V_1 = \ln(d) - \ln(p_1) - (1-d) \cdot \ln\left(\frac{y}{p_1} + a_1 \right),$$

$$V_2 = \ln(d) - \ln(p_2) - m - (1-d) \cdot \ln(a_2),$$

$$f_\varsigma(x) = \frac{\exp\left(e^{-x}\right)}{\left(1 + \exp\left(e^{-x}\right)\right)^2} \text{ and } F_\varsigma(x) = \frac{1}{1 + \exp\left(e^{-x}\right)}.$$

(III) OLS Method: Bias

Unobserved preference for car driving

$$x_2 = \alpha_0 + \alpha_1 \cdot z_1 + \alpha_2 \cdot z_2 + \alpha_3 \cdot z_3 + .. + \varepsilon$$

Car- km

Car-type

Income

Fuel price

error term

(IV) Overview of model types

Model type	Car-type choice	Car-km	*No-car* option?	Several cars possible?	Includes fixed costs?	Micro-economic foundation?	Researchers in this field
Discrete Choice (Probit)	Y	N	Y	Y	Y	N	McFadden NP2000
Continuous (OLS)	N	Y	N	N	N	partly	divers
Discrete-Continous Choice	Y	Y	N*	N	Y	Y	Dubin & McFadden (1984)
Multiple Discrete Continous Choice	Y	Y/N	N	Y	Y/N	Y	Bhat (2000)
Tobit	N	Y	Y	N	only in a special case	only in a special case	Tobin (1985) NP1981
Modified Multiple Discrete-Continuous Extreme Value Model (MDCEV) *incl. fixed costs*	N	Y	Y	N	Y	Y	(Reto Tanner, 2011)
Modified MDCEV may be extended to:	Y	Y	Y	Y	Y	Y	

Table 2: Overview of model types "car choice and use"

(V) Effects of different economic variables on the share of carless households

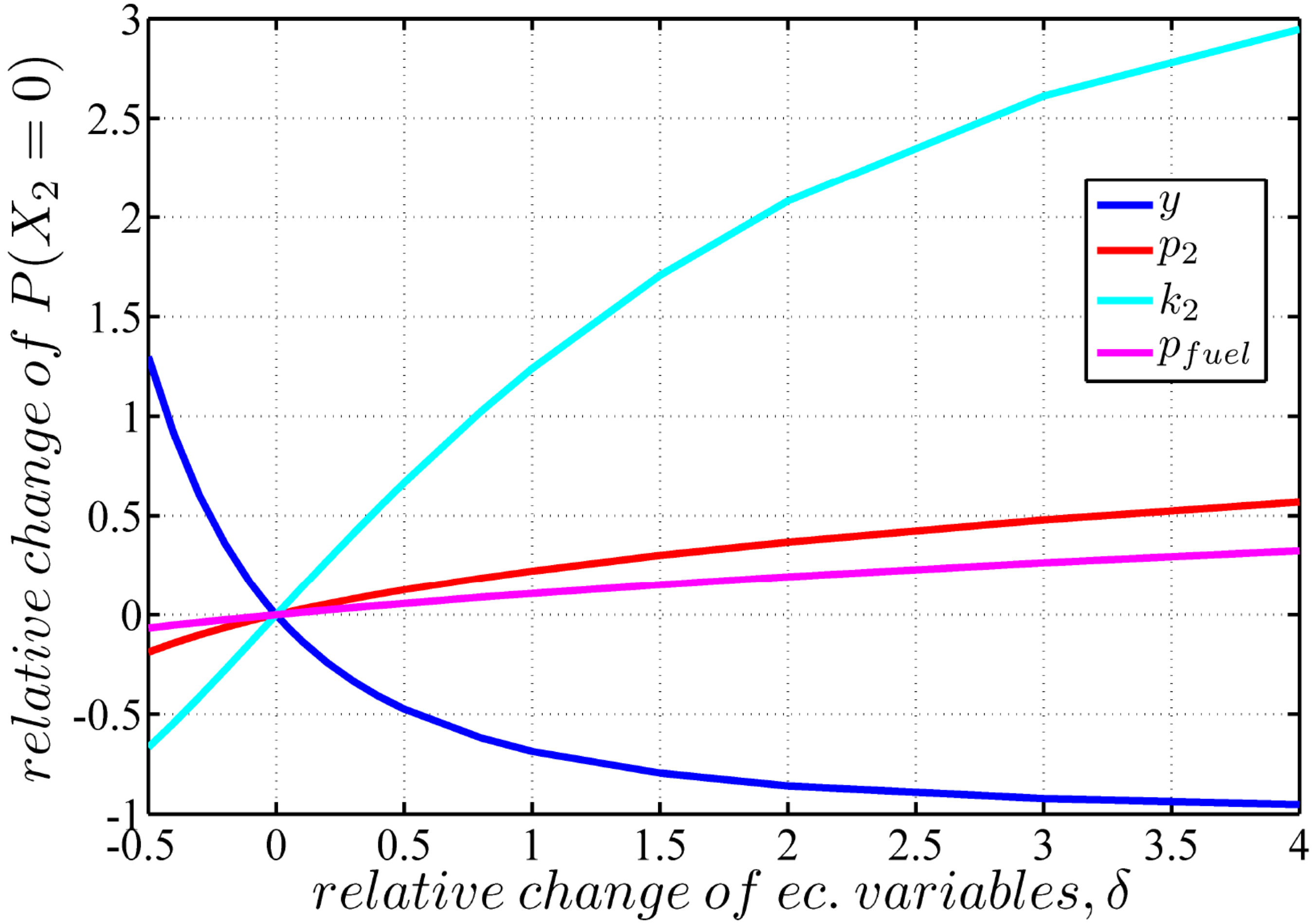


Fig. 24: Effects of different economic variables on the share of carless

(VI) Renominated... researchers

- **Daniel McFadden** was co-**Nobel laureate 2000** with James Heckman for developing theories and methods in discrete-choice modelling.
  One example is the Logit-Model. One of the first empirical applications of the Logit- was McFadden's study in the context of the introduction of the BART (public transportation network) in San Francisco in the mid 1970-ies.
- **Kenneth Train**, author of the book "Discrete Choice Methods with Simulation", a standard reference in this field.
- **Moshe Ben-Akiva** and **Steven Lerman**, Autors of the book "Discrete choice analysis", MIT Press, another standard reference in this field.
- **Michel Bierlaire**, developed the widely used software "Biogeme".