Welfare, Redistributive and Revenue Effects of Policies Promoting Fuel Efficient and Electric Vehicles

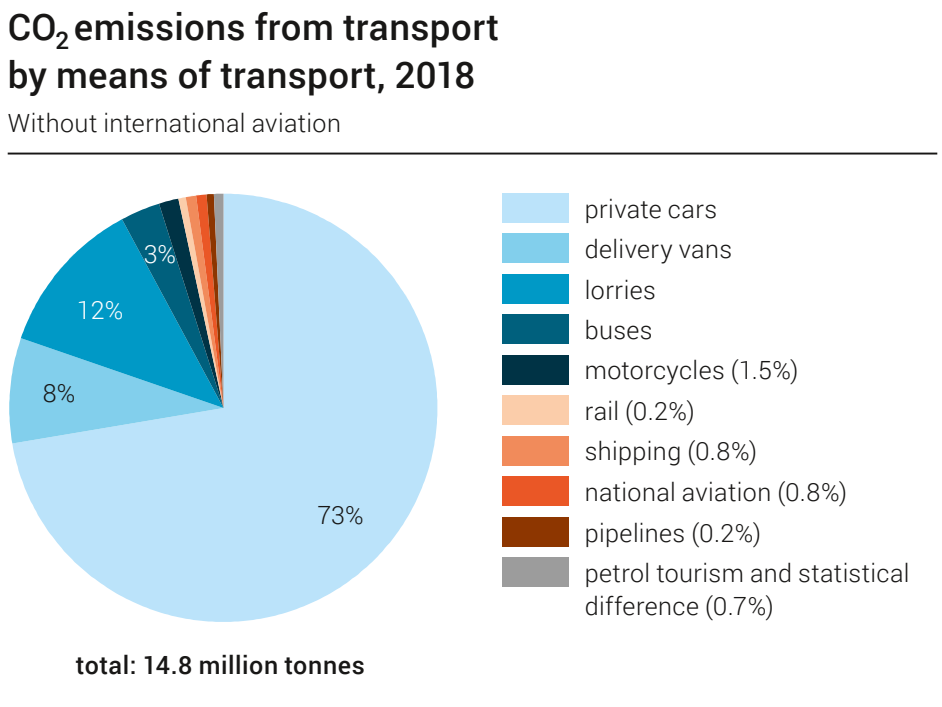
Patrick Bigler Doina Radulescu

University of Bern, Oeschger Centre for Climate Change Research and CESifo

June 7th, 2021
IAEE online conference 2021

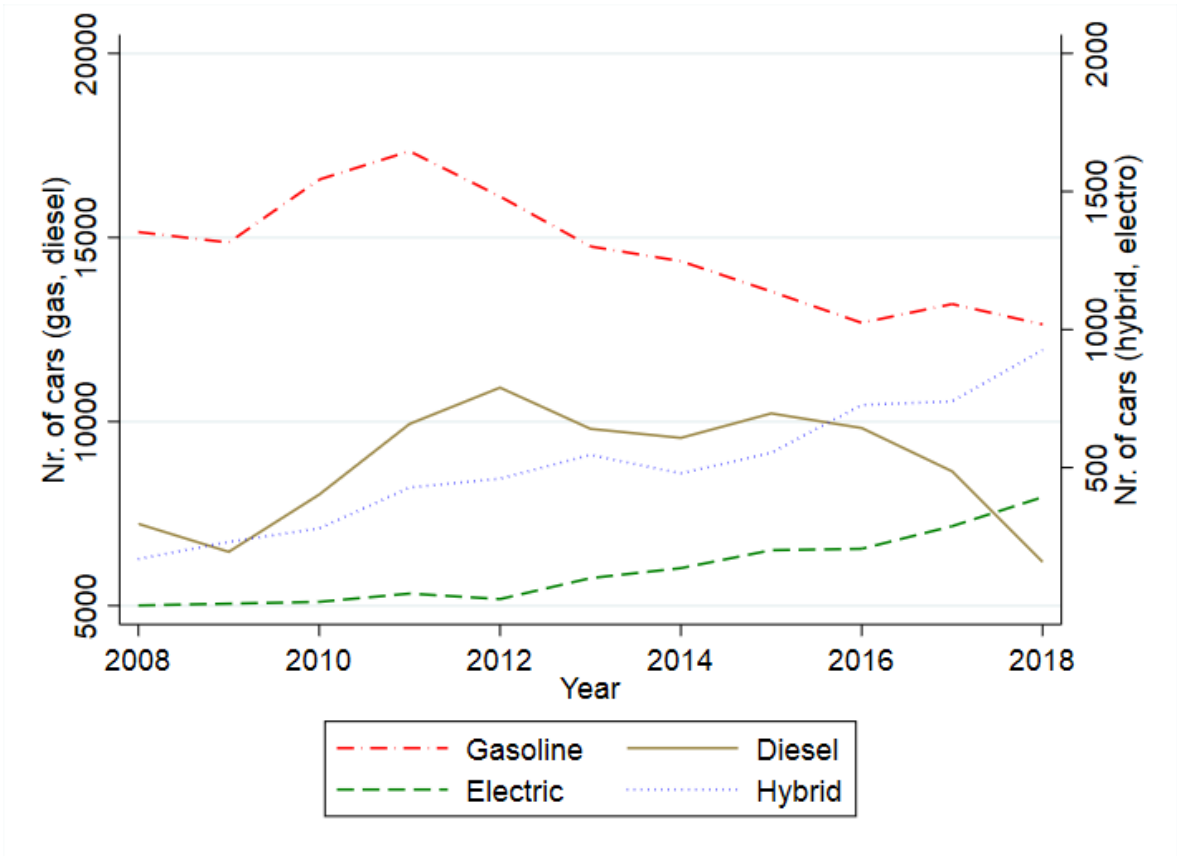
Motivation - CO_2 Emissions Transport Sector Switzerland

- Passenger car emissions increased by 44% since 2000 and represent 60% of road related emissions in Europe
- In Switzerland, the road transport sector accounts for around 39% of overall CO_2 emissions.
- Challenge: Achieve net zero emissions by 2050 while individual traffic projected to increase by 18% until 2040.



Motivation - Electric and Hybrid Vehicles

- Electric vehicles (EVs) and hybrid cars proposed as solution and supported by various government policies
- Even though EV adoption displays an increasing trend, only 0.5% of the world's vehicles are electric (CH: 0.62%).



Research Questions

- What factors drive households' preferences towards electric and hybrid cars?
- How likely are different policies to increase the uptake of environmentally friendly cars?
- What are the effects of these policies across the income distribution?

Contribution

- Estimate discrete choice model of vehicle demand using comprehensive dataset including household level and car characteristics.
- Assess the uptake and welfare implications of different policy changes based on estimated coefficients.
  - Fuel levy
  - EV purchase subsidy
  - Mileage tax
    - Missing revenue from fuel taxation (Mineralölsteuer) due to increased fuel efficiency
    - Increased road use (km driven) but less income to finance road infrastructure
    - EVs do not contribute to road financing but also need the infrastructure

Literature

Effect of government policies on adoption of EV and HV

- Beresteanu and Li (2011); Chandra, Gulati and Kandlikar (2010); Gallagher and Muehlegger (2011); Li, Linn and Spiller (2013); Mian and Sufi (2012) or Muehlegger and Rapson (2018); Langbroek, Franklin and Susilo (2016); Szierchula, Bakker, Maat and van Wee (2014)

Consumer attitudes and perceptions towards these technologies

- Egbue and Long (2012); Krause, Carley, Lane and Graham (2013)

Peer effects

- Jannson, Pettersson, Mannberg, Brannlund, Lindgren (2017)

What does an electric vehicle replace

- Xing, Leard and Li (2021), Muehlegger and Rapson (2020)

Literature - continued

Equity aspects

- Borenstein and Davis (2016)

Effect of gasoline taxes or fuel economy standards on vehicle choice

- Bento, Goulder, Jacobsen, von Haefen (2009); Grigolon, Reynaert and Verboven (2018); Bento, Knittel, Jacobsen, van Benthem (2019)

Mileage tax

- Davis and Sallee (2020)

Registration taxes in Switzerland

- Alberini and Bareit (2019)

Demand model(Grigolon, Reynaert, Verboven,2018; Xing, Leard and Li, 2021)

Household $i's$ utility from purchasing new vehicle type j :

$$u_{ij} = \beta^x x_j + \beta^z z_i x_j - \alpha_1(log(p_j) + \gamma(G_{ij} + T_j)) + \alpha_2 \frac{log(p_j)}{y_i} + \epsilon_{ij} \quad (1)$$

Variable Costs:

$$G_{ij} = \rho m_i [e_j g_j (1 + \tau_j^g) + \tau_j^m] \quad (2)$$

$$T_j = \rho t_j \quad (3)$$

Capitalization factor:

$$\rho = \sum_{s=1}^{S} \frac{1}{(1+r)^s} \quad (4)$$

r=6%; S=10 years
Assumption:

- Households take prices and taxes as given
- Future expectation is based on today's value
- Inelastic mileage

Conditional Logit

Probability of household i to choose vehicle type j:

$$P_{ij} = \frac{e^{\beta^x x_j + \beta^z z_i x_j - \alpha_1(log(p_j) + \gamma(G_{ij} + T_j)) + \alpha_2 \frac{log(p_j)}{y_i} + \epsilon_{ij}}}{\sum_j e^{\beta^x x_j + \beta^z_j z_i x_j - \alpha_1(log(p_j) + \gamma(G_{ij} + T_j)) + \alpha_2 \frac{log(p_j)}{y_i} + \epsilon_{ij}}} \quad (5)$$

ϵ_{ij} i.i.d. Type 1 extreme value distributed

Choice Set

Each household's choice set consist of 489 theoretical options based on fuel type (Gasoline, Diesel, Hybrid, Electric) and make-model segmentation (i.e. VW Golf, Audi A6)

- include car type fe; brand country of origin fe
- address price endogeneity by using a cost shifter - annual penalties for fleet wide fuel efficiency standards car importers are subject to.

The Dataset

We have access to several datasets for households in the Canton of Bern, merging data from

1. Tax office of Bern
   - Income, wealth, household size, marital status, age
2. Road Traffic Office Canton of Bern
   - Data on new car registrations between 2008-2019 (ownership in 2019)
3. Eurotax, Federal Roads Office (Switzerland) and LEMNET
   - Vehicle prices, Fuel efficiency, engine power, car size
   - Data on number and location of EV charging stations

Summary Statistics

Gasoline

	N	Mean	Sd	Min.	Median	Max.
Household income (TCHF)	16,005	111	556	0	90	68,364
Household wealth (TCHF)	16,005	680	5,825	0	311	648,887
Age (main income source)	16,005	55	16	21	57	99
Suggested car price (TCHF)	16,005	31	20	8	28	210
Distance driven (KM/year)	16,005	11,259	2,084	4,132	11,183	29,715
Fuel Economy (CHF/100km)	16,005	9	2	6	9	25
CO_2 emission (g/km)	16,005	135	27	88	129	359
Distance to EV charging station (m)	16,005	1,317	1,292	1	787	9,679
Household size	16,005	2	1.05	1	2	5
Urbanity of home	16,005	1.91	.88	1	2	3

Electric

	N	Mean	Sd	Min.	Median	Max.
Household income (TCHF)	380	170	141	7	138	1,092
Household wealth (TCHF)	380	1,495	3,844	0	711	63,082
Age (main income source)	380	55	13	22	54	119
Suggested car price (TCHF)	380	53	25	24	46	104
Distance driven (KM/year)	380	10,838	2,181	4,466	10,663	23,351
Fuel Economy (CHF/100km)	380	4	1	3	4	6
CO_2 emission (g/km)	380	0	0	0	0	0
Distance to EV charging station (m)	380	1,313	1,310	37	791	7,482
Household size	380	2.47	1.2	1	2	5
Urbanity of home	380	1.84	.85	1	2	3

Conditional logit - estimated coefficients

	(1)	(2)	(3)
Car price (log)	−0.227 ***	−0.034	−2.116 ***
	(0.03)	(0.04)	(0.11)
Price (log) / income	0.002+	0.003+	0.002+
	(0.00)	(0.00)	(0.00)
Variable costs (log pv)	−0.684 ***	−0.520 ***	−0.350 ***
	(0.08)	(0.10)	(0.10)
Engine power (KW)	−0.000	−0.001+	0.007 ***
	(0.00)	(0.00)	(0.00)
Car height	0.453 ***	0.466 ***	−1.550 ***
	(0.09)	(0.13)	(0.16)
Car weight	0.000	−0.001 ***	0.001 ***
	(0.00)	(0.00)	(0.00)
Hybrid engine	−0.751 ***	−0.690 ***	−0.205
	(0.16)	(0.16)	(0.16)
Electric engine	−1.983 ***	−1.731 ***	−1.178 ***
	(0.23)	(0.24)	(0.24)
Diesel engine	−0.760 ***	−0.732 ***	−0.567 ***
	(0.02)	(0.02)	(0.02)
Car size	−0.127 ***	−0.033	−0.006
	(0.02)	(0.02)	(0.02)
Size heterogeneity			
2 Persons	0.163 ***	0.187 ***	0.184 ***
	(0.02)	(0.02)	(0.02)
3 Persons	0.315 ***	0.362 ***	0.359 ***
	(0.03)	(0.03)	(0.03)
4 Persons	0.516 ***	0.582 ***	0.577 ***
	(0.02)	(0.03)	(0.03)
5+ Persons	0.714 ***	0.793 ***	0.785 ***
	(0.04)	(0.04)	(0.04)
KW heterogeneity			
40-60 years old	−0.003 ***	−0.003 ***	−0.003 ***
	(0.00)	(0.00)	(0.00)
60+ years old	−0.005 ***	−0.005 ***	−0.005 ***
	(0.00)	(0.00)	(0.00)
EV effects			
EV agglomeration	0.311*	0.311*	0.310*
	(0.14)	(0.14)	(0.14)
EV rural	−0.023	−0.025	−0.026
	(0.15)	(0.15)	(0.15)
Distance to EV	−0.030	−0.029	−0.029
	(0.02)	(0.02)	(0.02)
Nb. Charging (5km)	0.007*	0.007*	0.007*
	(0.00)	(0.00)	(0.00)
EV 2018	0.133	0.088	0.123
	(0.14)	(0.14)	(0.14)
EV 2019	1.357 ***	1.307 ***	1.359 ***
	(0.13)	(0.13)	(0.13)
Control function	*No*	*No*	*Yes*
Observations	9,816,000	9,816,000	9,816,000
Nr. of cases	23,074	23,074	23,074
Log Likelihood	−136,093.3	−134,604	−134,380.7
Car type fe	*No*	*Yes*	*Yes*
Car brand (country)	*No*	*Yes*	*Yes*

+p<0.1; * p<0.05; ** p<0.01; *** p<0.001

Coefficients based on estimated conditional and mixed logit model. Estimated standard errors in parentheses. Model (1) - (3) do not have random coefficients. Coefficients in Model (1) and (5) are based on control function approach with estimation of the pricing equation in a separate model based on cost shifters in a first step.

Conditional logit - predicted probabilites

	Overall	1st inc. quartile	2nd inc quartile	3rd inc quartile	4th inc quartile
Gasoline	0.6719	0.6883	0.6744	0.6645	0.6606
Diesel	0.2610	0.2463	0.2594	0.2679	0.2703
Electro	0.0167	0.0175	0.0162	0.0162	0.0170
Hybrid	0.0504	0.0479	0.0514	0.0514	0.0522

Notes: 1st quartile: income $<$ 62.9 kCHF, 2nd quartile: 62.9$>=$income$<$ 93.67 kCHF, 3rd quartile: 93.67$>=$ income$<$131.7 kCHF and 4th quartile: income $>=$ 131.7 kCHF..

Increase in fossil fuel levy by 0.12 CHF/l - Change in Probabilities

	Overall	1st inc. quartile	2nd inc quartile	3rd inc quartile	4th inc quartile
Gasoline	-0.00077	-0.00077	-0.00076	-0.00077	-0.00078
Diesel	0.00028	0.00027	0.00028	0.00028	0.00028
Electro	0.00030	0.00031	0.00029	0.00029	0.00030
Hybrid	0.00020	0.00019	0.00020	0.00021	0.00021

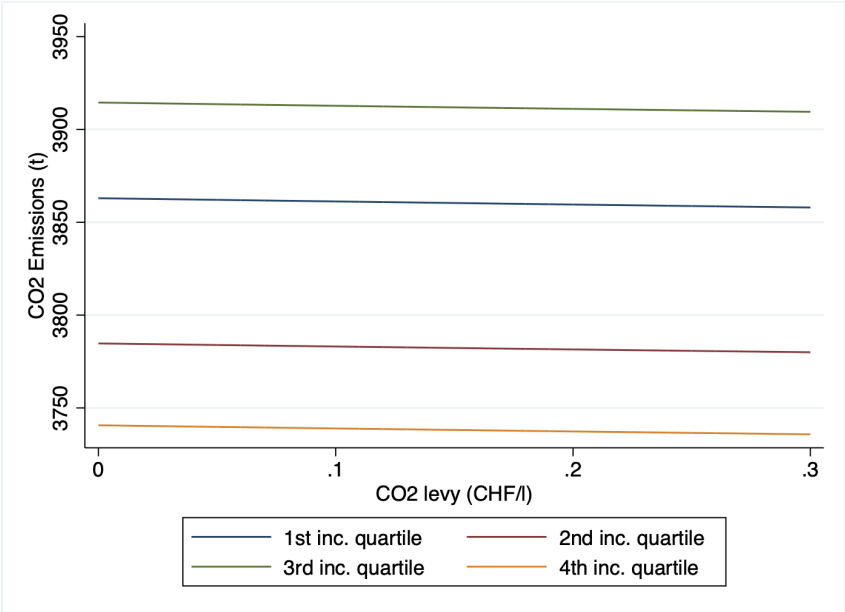
Notes: 1st quartile: income $<$ 62.9 kCHF, 2nd quartile: 62.9$>=$income$<$ 93.67 kCHF, 3rd quartile: 93.67$>=$ income$<$131.7 kCHF and 4th quartile: income $>=$ 131.7 kCHF..

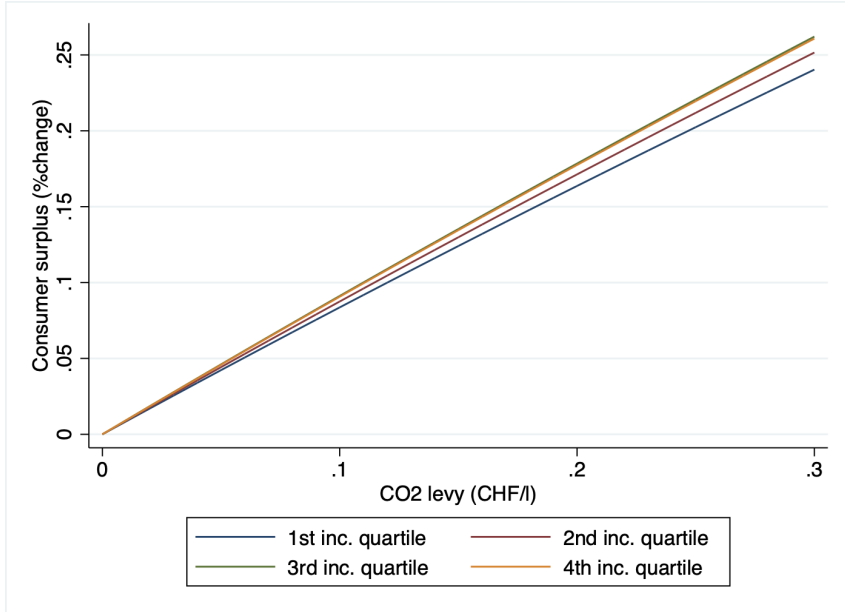
Increase in fossil fuel levy by 0.12 CHF/l - Welfare analysis

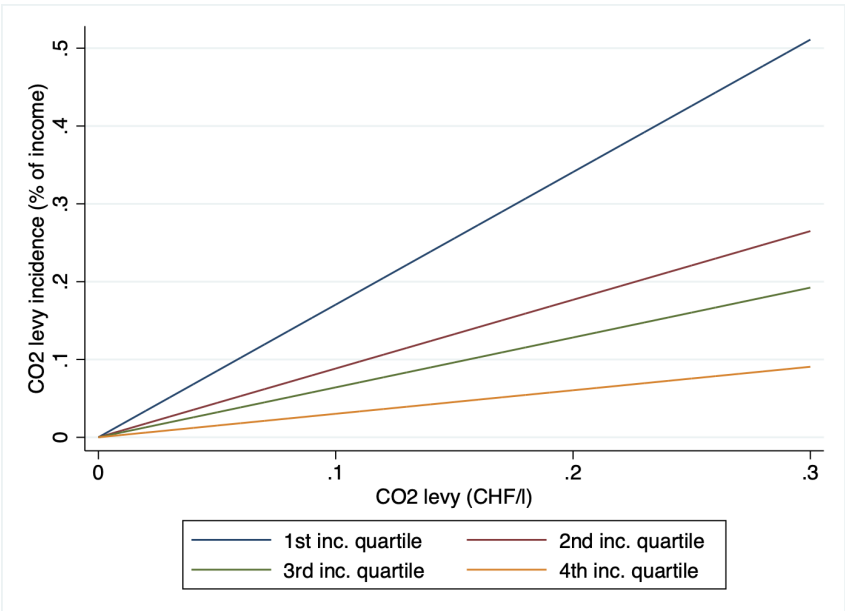
	Cons. surplus (MCHF)	CS (% change)	CO_2 levy (kCHF)	Levy incidence (%)	Car taxes (CHF)	CO_2 (t)	CO_2 (% change)
1st inc quartile	-1.530	-0.0999	195.65	0.204	-228.33	-2.084	-0.054
2nd inc quartile	-1.585	-0.105	191.34	0.106	-217.40	-1.978	-0.052
3rd inc quartile	-1.710	-0.109	197.7	0.077	-223.07	-2.079	-0.055
4th inc quartile	-2.044	-0.108	188.89	0.036	-231.23	-2.027	-0.054
Total	-6.870	-0.106	773.56	0.073	-900.02	-8.171	-0.053

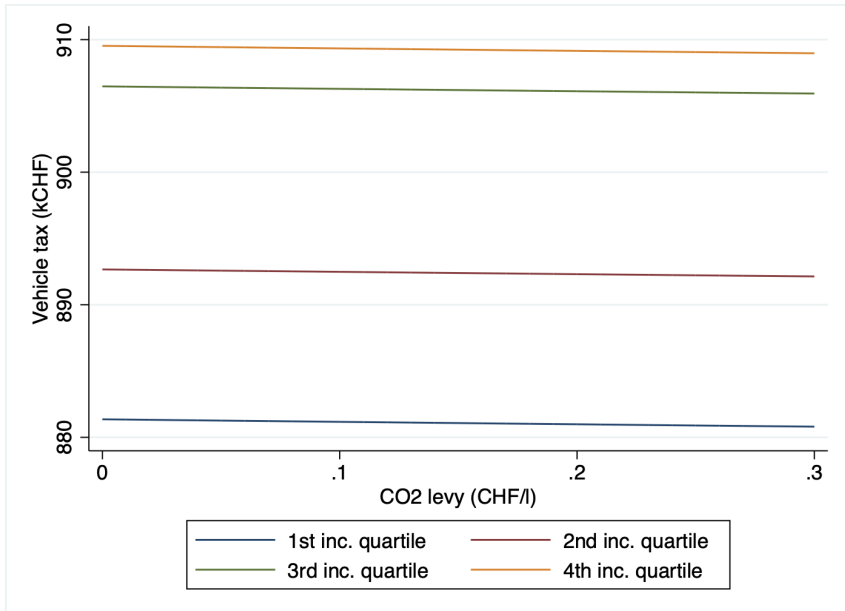
Notes: 1st quartile: income $<$ 62.9 kCHF, 2nd quartile: 62.9$>=$income$<$ 93.67 kCHF, 3rd quartile: 93.67$>=$ income$<$131.7 kCHF and 4th quartile: income $>=$ 131.7 kCHF. Consumer surplus based on logsum formula.

CO_2 levy simulation - Consequences









Introduction of mileage tax - Calculation

- Assume annual fuel tax payment per car should remain at 2010 level
- Calculate hypothetical tax revenue based on annual car registration growth rate
- Calculate difference between hypothetical and actual tax revenue. Division by amount of KM driven results in the mileage tax of **0.023 CHF/km**

Introduction of mileage tax (0.023 CHF/km) - Change in Probabilities

	Overall	1st inc. quartile	2nd inc quartile	3rd inc quartile	4th inc quartile
Gasoline	0.0018	0.0018	0.0018	0.0018	0.0018
Diesel	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002
Electro	-0.0012	-0.0012	-0.0011	-0.0011	-0.0012
Hybrid	-0.0004	-0.0004	-0.0004	-0.0005	-0.0005

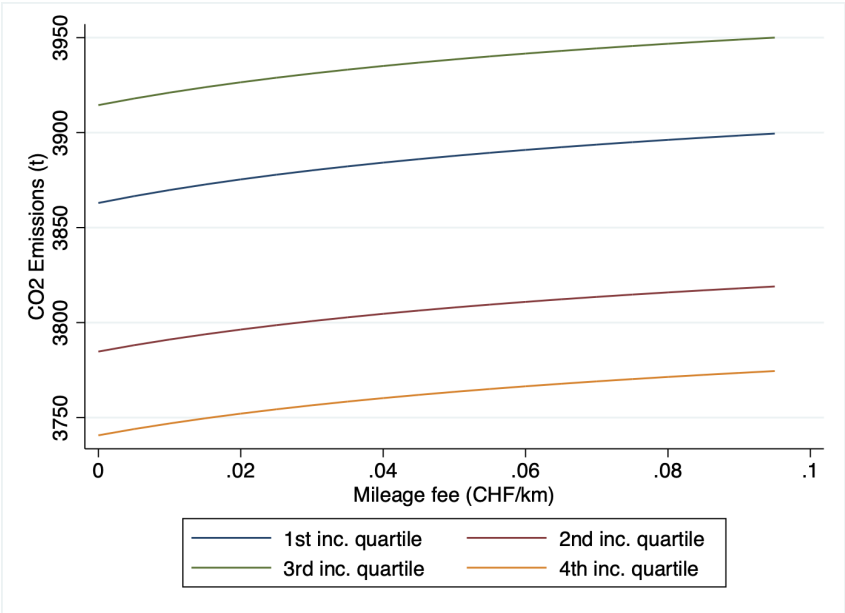
Notes: 1st quartile: income $<$ 62.9 kCHF, 2nd quartile: 62.9$>=$income$<$ 93.67 kCHF, 3rd quartile: 93.67$>=$ income$<$131.7 kCHF and 4th quartile: income $>=$ 131.7 kCHF..

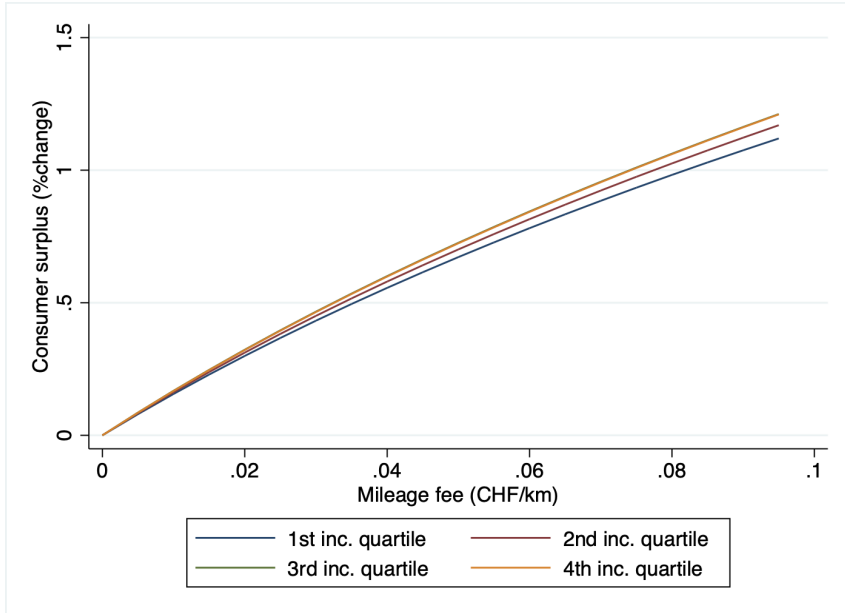
Introduction of mileage tax (0.023 CHF/km) - Welfare analysis

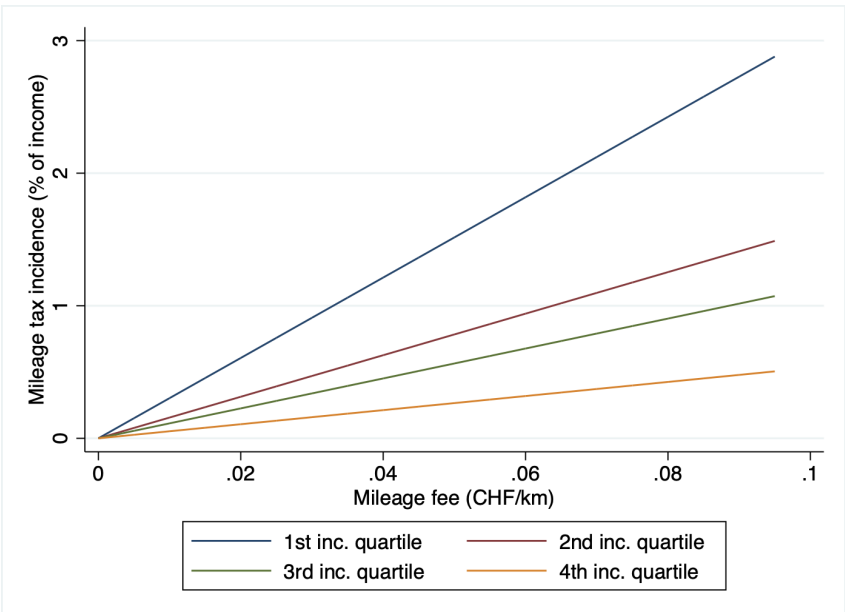
	Cons. surplus (MCHF)	CS (% change)	Mileage tax (kCHF)	Incidence (%)	Car taxes (CHF)	CO_2 (t)	CO_2 (% change)
1st inc quartile	-5.212	-0.340	666.69	0.696	3,172	13.924	0.360
2nd inc quartile	-5.375	-0.355	650.21	0.360	3,046	13.004	0.344
3rd inc quartile	-5.764	-0.367	666.65	0.260	3,039	13.478	0.344
4th inc quartile	-6.901	-0.367	636.39	0.122	3,023	12.807	0.342
Total	-23.252	-0.358	2,619.92	0.248	12,279	53.213	0.348

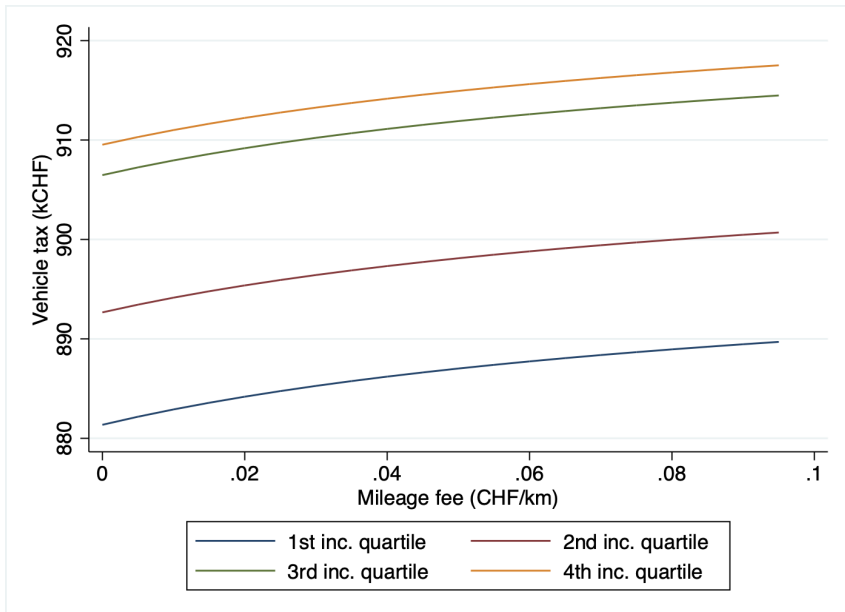
Notes: 1st quartile: income $<$ 62.9 kCHF, 2nd quartile: 62.9$>=$income$<$ 93.67 kCHF, 3rd quartile: 93.67$>=$ income$<$131.7 kCHF and 4th quartile: income $>=$ 131.7 kCHF.. Consumer surplus based on logsum formula.

Mileage tax simulation - Consequences









EV subsidy (4k CHF) - Change in Probabilities

	Overall	1st inc. quartile	2nd inc quartile	3rd inc quartile	4th inc quartile
Gasoline	-0.0029	-0.0031	-0.0028	-0.0027	-0.0028
Diesel	-0.0010	-0.0010	-0.0010	-0.0010	-0.0010
Electro	0.0041	0.0043	0.0040	0.0039	0.0041
Hybrid	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002

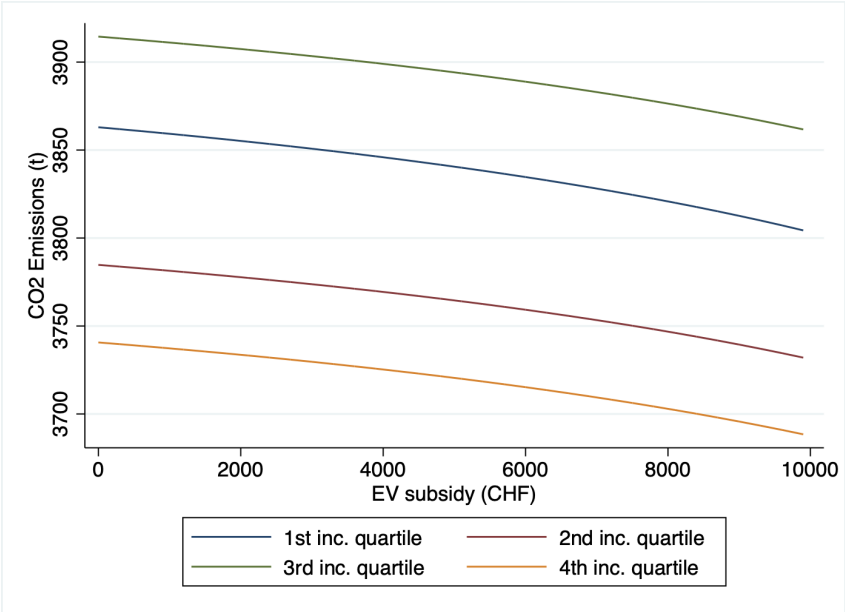
Notes: 1st quartile: income $<$ 62.9 kCHF, 2nd quartile: 62.9$>=$income$<$ 93.67 kCHF, 3rd quartile: 93.67$>=$ income$<$131.7 kCHF and 4th quartile: income $>=$ 131.7 kCHF.

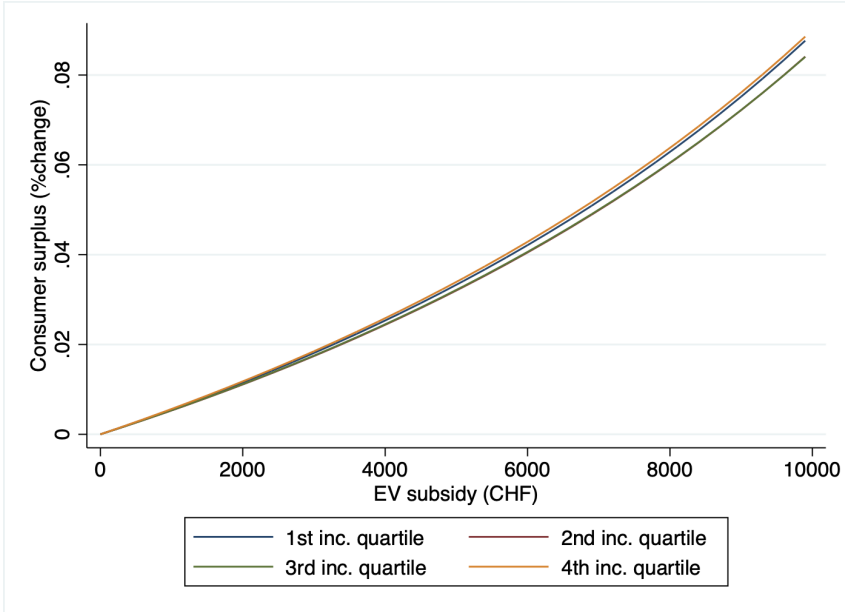
EV subsidy (4k CHF) - Welfare analysis

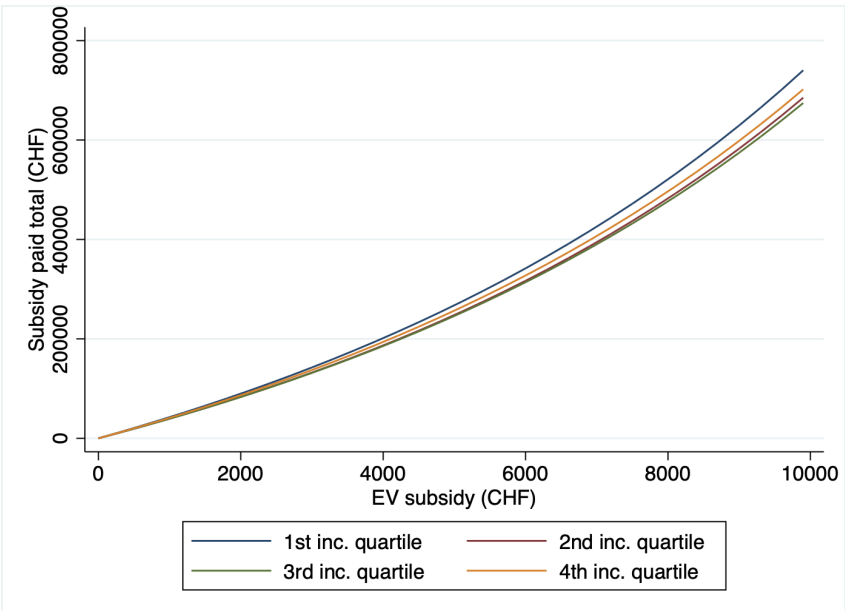
	Cons. surplus (kCHF)	CS (% change)	Total subsidy (kCHF)	Car taxes (kCHF)	CO_2 emission (t)	CO_2 (% change)
1st inc quartile	387.93	0.025	201.53	-3.021	-17.057	-0.44
2nd inc quartile	369.37	0.024	186.90	-2.813	-15.376	-0.406
3rd inc quartile	384.51	0.025	185.64	-2.785	-15.485	-0.396
4th inc quartile	487.83	0.026	193.85	-2.905	-15.370	-0.411
Total	1,629.63	0.025	767.91	-11.524	-63.289	-0.414

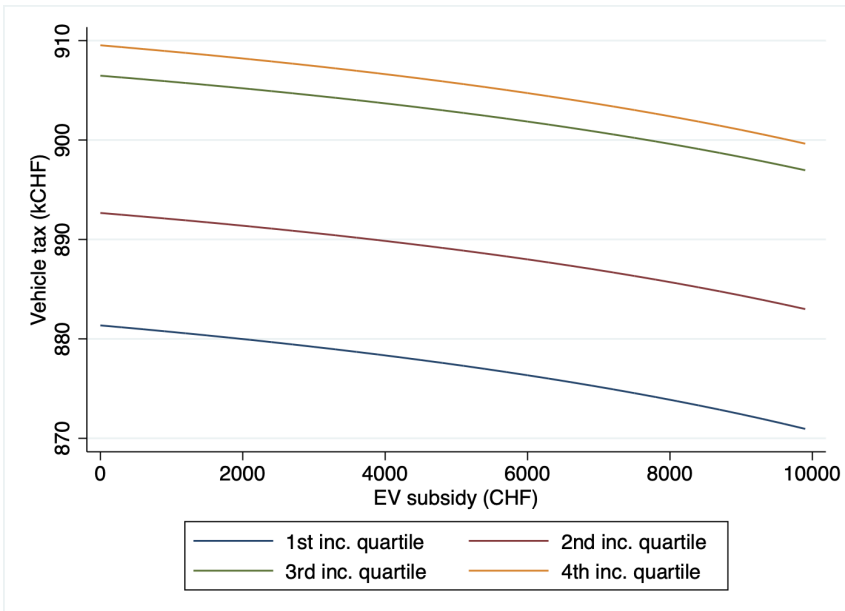
Notes: 1st quartile: income $<$ 72.5 kCHF, 2nd quartile: 72.5$>=$income$<$ 101.6 kCHF, 3rd quartile: 101.6$>=$ income$<$138.6 kCHF and 4th quartile: income $>=$ 138.6 kCHF. Consumer surplus based on logsum formula.

EV subsidy - Consequences









Conclusion

- Overall probability to acquire a gasoline, hybrid or EV amounts to 67%, 5% and 1.7% respectively
- Increase in fuel tax
  - Decreases consumer surplus; small reduction in CO_2 emissions of the new car fleet; regressive effects
- Introduction of EV subsidy
  - Increases consumer surplus; significantly decreases CO_2 emissions of the new car fleet; requires moderate outlays
- Introduction of mileage tax
  - Increases probability to buy gasoline driven cars; increases CO_2 emissions of the new car fleet; highly regressive

Supplementary Material

Welfare estimation for different counterfactuals

Small and Rosen (1981) approach:

$$\Delta E(CS_i) = \frac{1}{a_i}[ln(\sum_{j=1}^{J^1} e^{V_{ij}^1}) - ln(\sum_{j=1}^{J^0} e^{V_{ij}^0})] \tag{6}$$

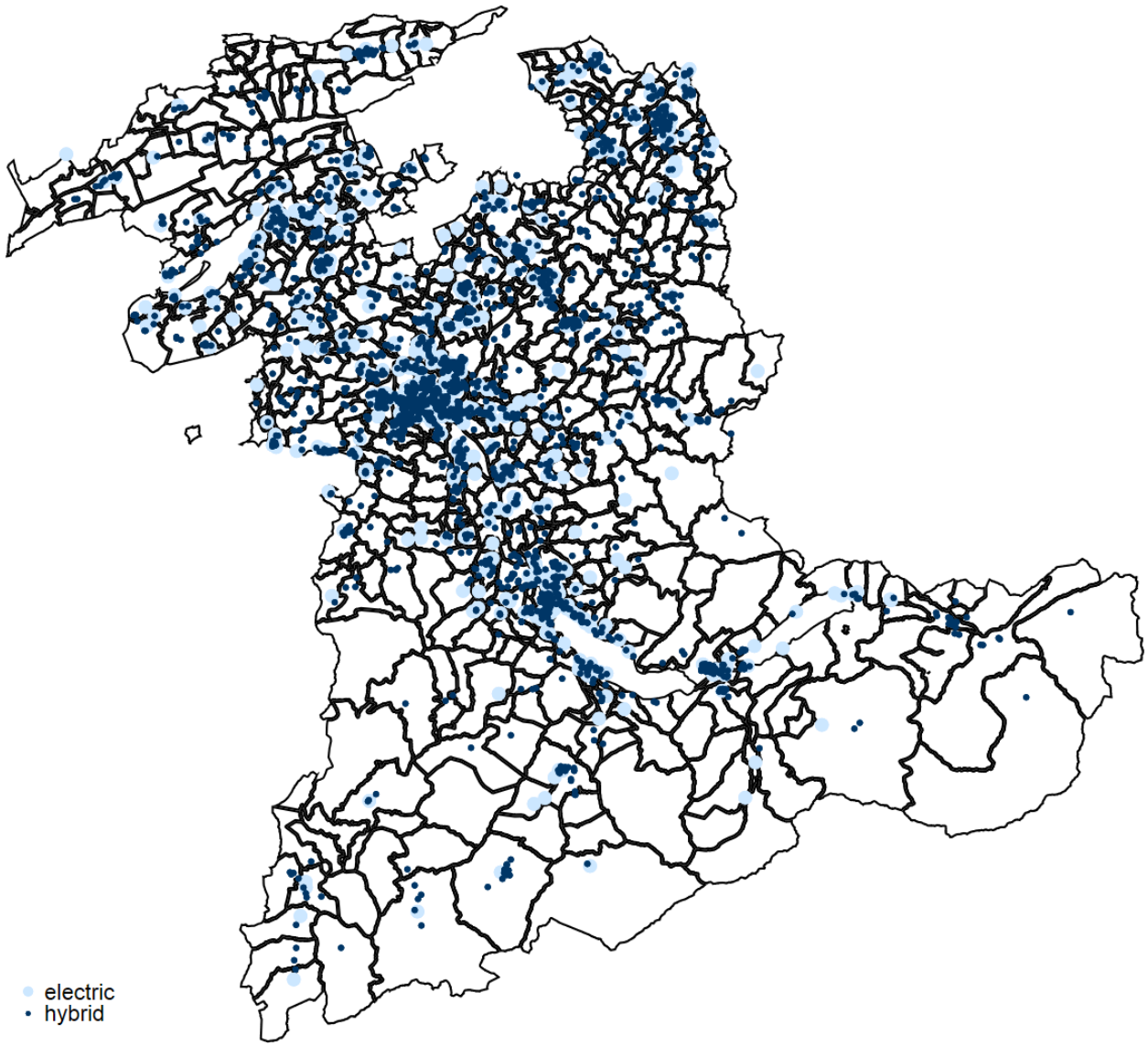
V_{ij} : deterministic household utility in the status quo (state 0) and counterfactual (state 1).
a_i = marginal utility of income.

$$a_i = -\frac{\partial U_{ij}}{\partial p_j} = \frac{1}{p}(\alpha_1 - \frac{\alpha_2}{y}) \tag{7}$$

Three policy experiments:

- Fossil fuel levy
- Introduction of a mileage tax
- Upfront subsidy for EV car purchase

Spatial Distribution of EVs and Hybrid Cars



Summary Statistics

Overall Sample

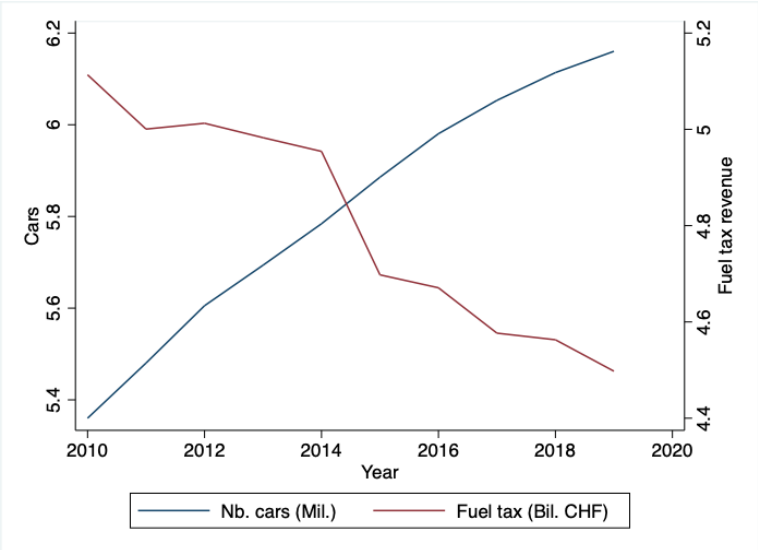
	N	Mean	Sd	Min.	Median	Max.
Household income (TCHF)	23,074	114	467	0	94	68,364
Household wealth (TCHF)	23,074	691	5,046	0	322	648,887
Age (main income source)	23,074	55	15	21	56	119
Suggested car price (TCHF)	23,074	35	20	8	32	210
Distance driven (KM/year)	23,074	12,342	2,875	4,132	11,961	29,715
Fuel Economy (CHF/100km)	23,074	9	2	3	9	25
CO_2 emission (g/km)	23,074	132	32	0	129	359
Distance to EV charging station (m)	23,074	1,320	1,300	1	789	9,679
Household size	23,074	2.1	1.11	1	2	5
Urbanity of home	23,074	1.91	.88	1	2	3

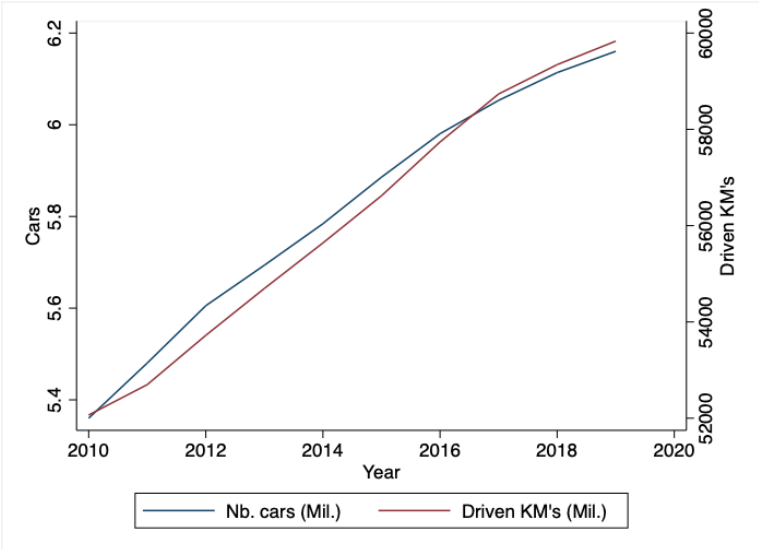
Prediction Evaluation

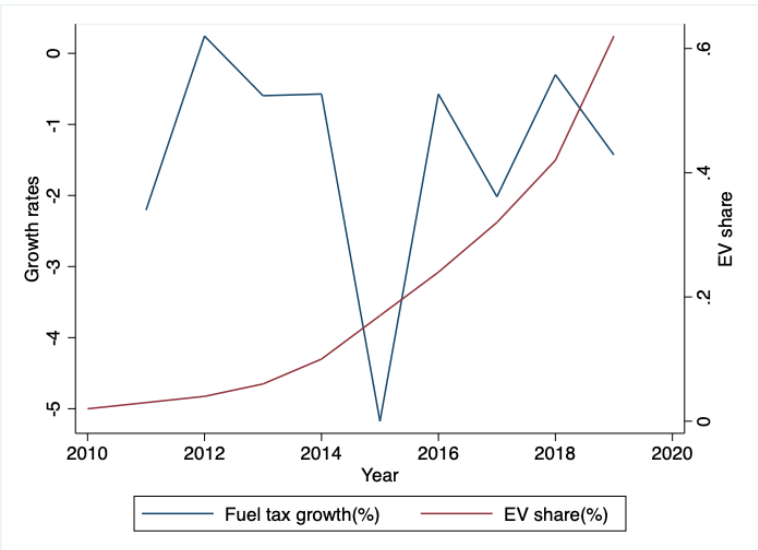
Income	Gasoline predicted (N)	Gasoline actual (N)	EV predicted (N)	EV actual (N)
1st inc. quartile	3,971	4,450	100	52
2nd inc quartile	3,890	4,045	93	55
3rd inc quartile	3,833	3,853	93	68
4th inc quartile	3,810	3,648	97	205
Overall χ^2_3	65.49		Overall χ^2_3	136.61
2nd & 3rd quartile χ^2_1	6.74		2nd & 3rd quartile χ^2_1	35.45

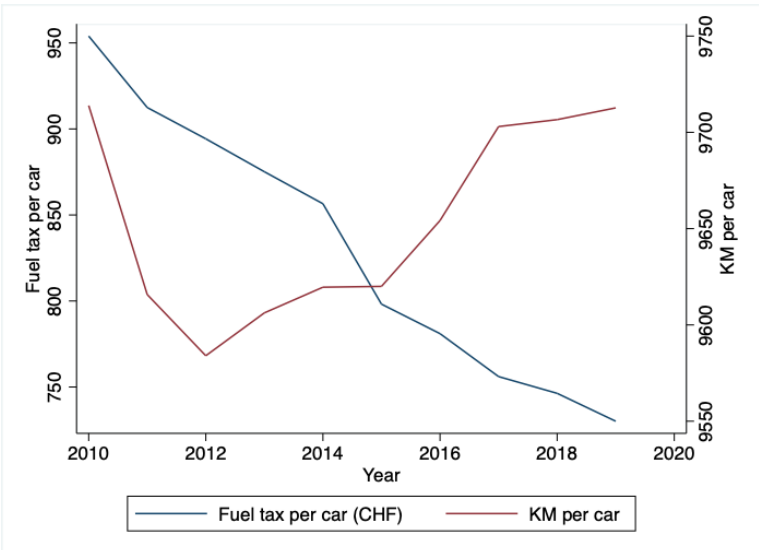
Notes: The critical values are 7.815 and 3.841 for the χ^2_3 and χ^2_1 with a 95% significance level and 11.345 and 6.635 with a 99% significance level respectively.

Mileage tax - Graphical motivation









Notes: Based on several statistics from the Swiss department of statistics.