Institute of Transport Economics
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Good Chargers? The impact of electric vehicle density on local grid costs

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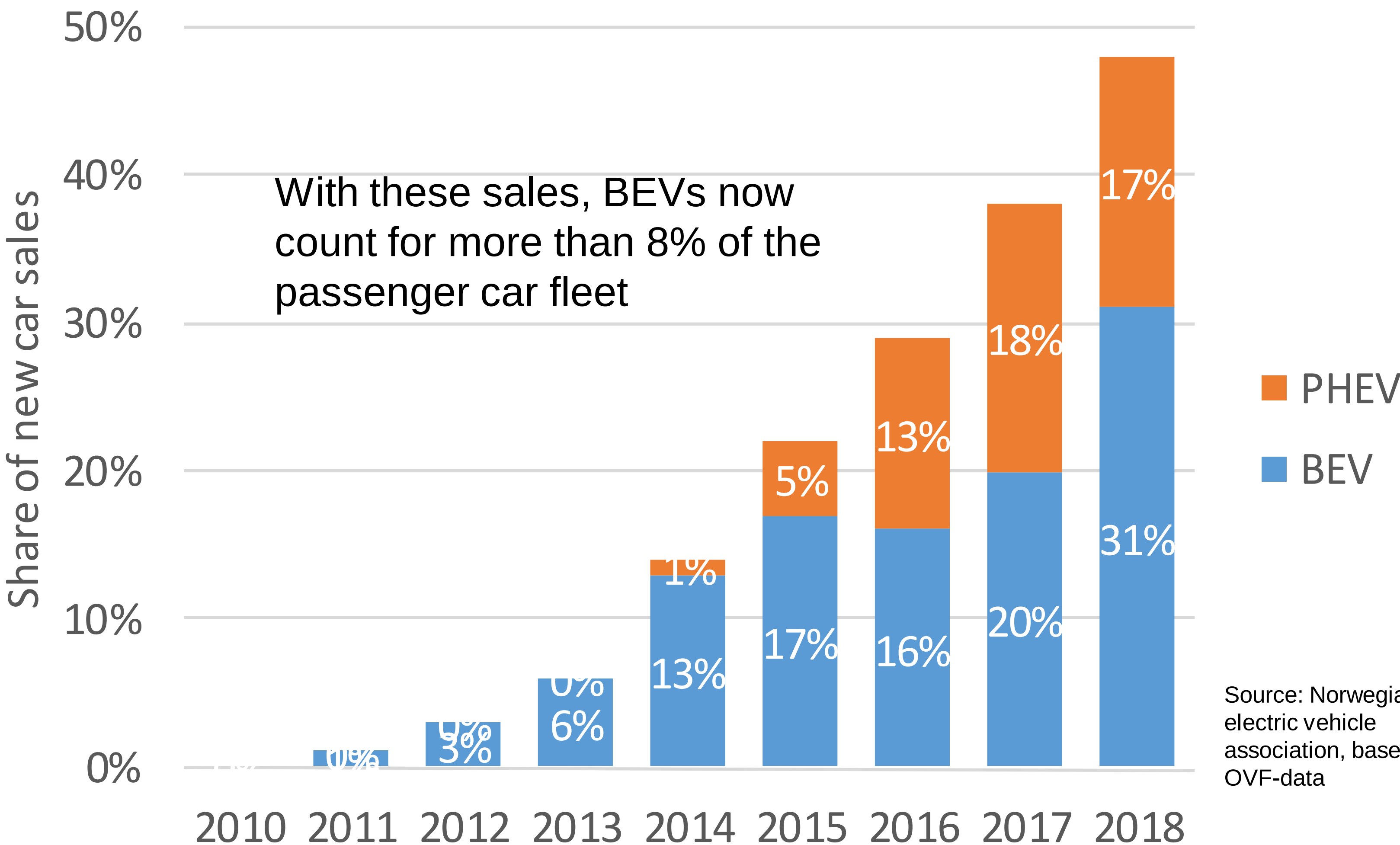
Research in motion

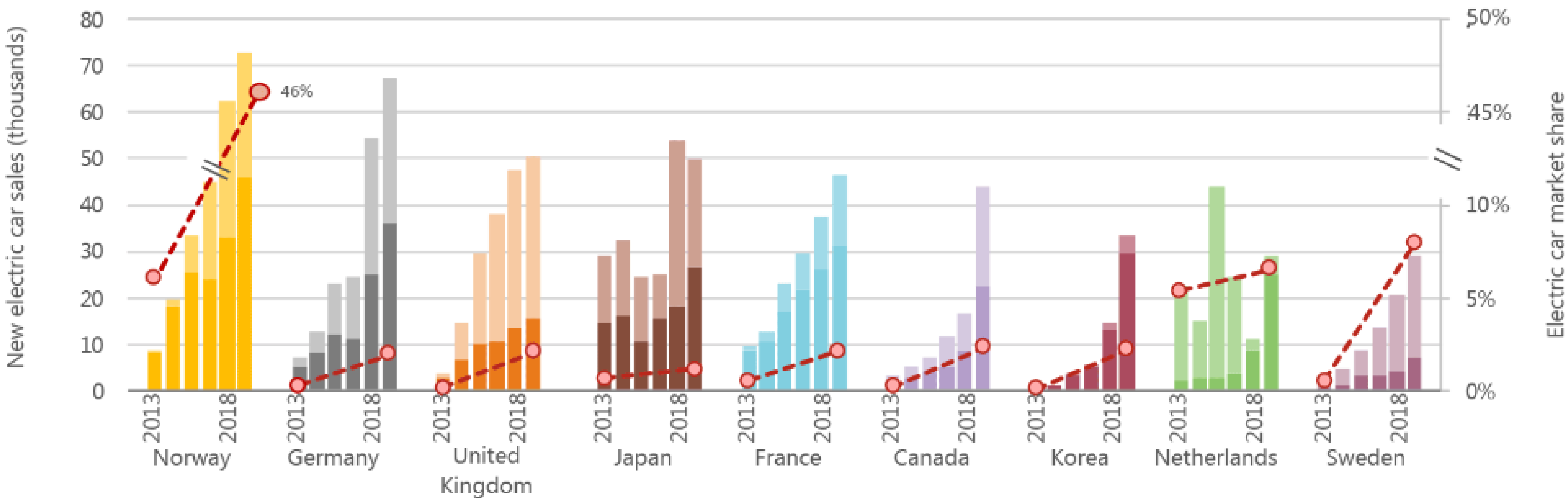
MOTIVATION AND BACKGROUND

Almost half of all new cars in Norway were plug-in electric in 2018



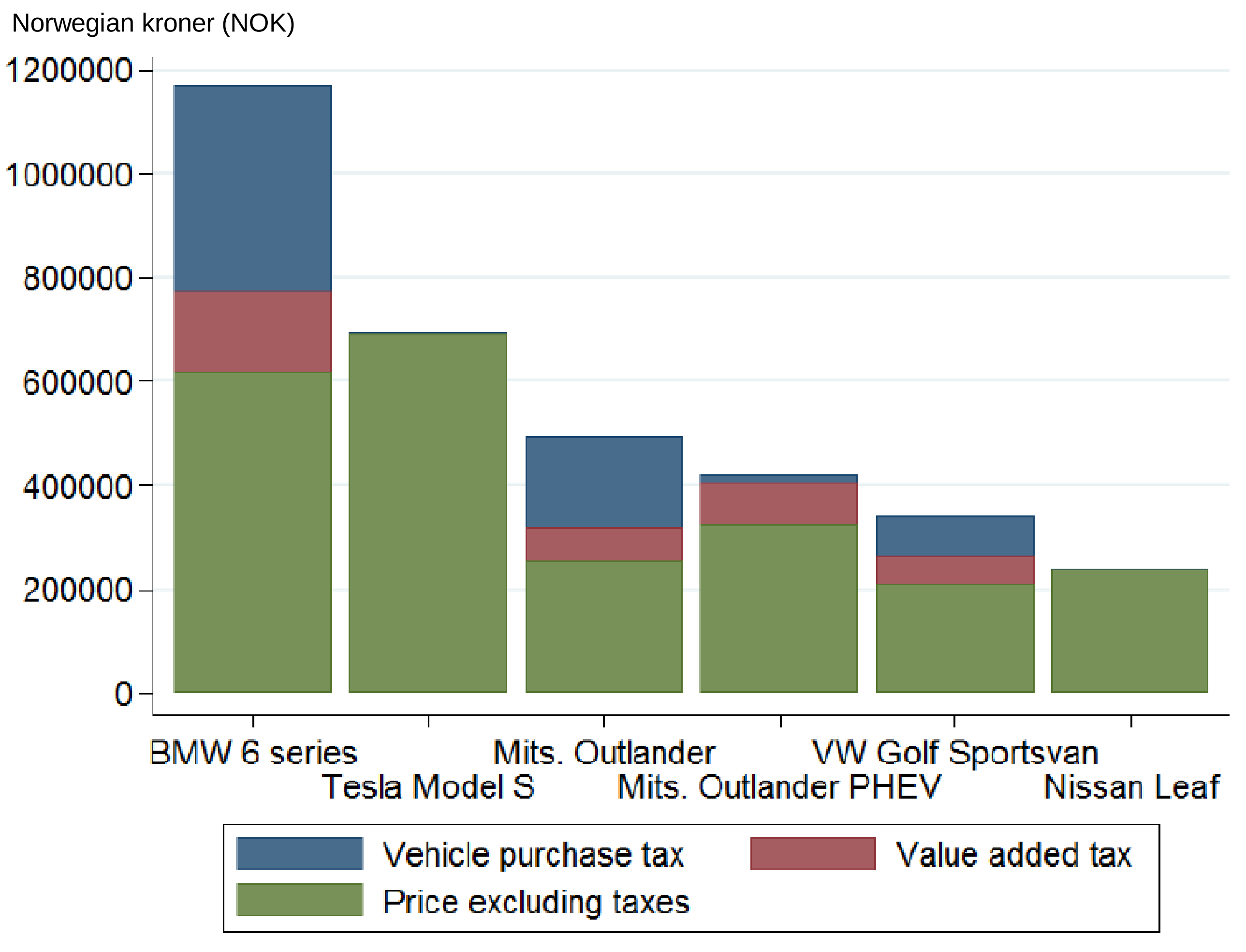
Source: Norwegian electric vehicle association, based on OVF-data

This gives Norway the highest market share of EVs in the world, and the highest absolute number of EVs in Europe



Source: IEA (2019), "Global EV Outlook 2019": IEA analysis based on country submissions, complemented by ACEA (2019); EAFO (2019); EV Volumes (2019); Marklines (2019); OICA (2019)

The main reason: Conventional cars are heavily taxed



Source: Johansen (2019), based on OVF-data

EVs needed to reach climate goals, but can lead to higher grid costs and tariffs

There exists a literature that warns that EV charging will cause substantial future costs to the local grid

Examples:

De Hoog et al (2015). Optimal charging of electric vehicles taking distribution network constraints into account. *IEEE Transactions on Power Systems*

Haidar et al (2014). Technical challenges for electric power industries due to grid-integrated electric vehicles in low voltage distributions: A review. *Energy Conversion and Management*

Hattam et al (2017). Green neighbourhoods in low voltage networks: measuring impact of electric vehicles and photovoltaics on load profiles. *Journal of Modern Power Systems and Clean Energy*

Our motivation and contribution

- If indeed uncoordinated charging leads to higher costs to DSOs, then Norwegian data would be the first place to investigate.

- To our knowledge, such an empirical analysis has not been done before on real data on the world's highest level of EV density to date.

- Implications for regulation, pricing and assessing GHG abatement costs

Based on this motivation, our research questions are:

1. What are the *marginal costs* inflicted on DSOs when the number of EVs increases?

2. Through which *mechanisms*, i.e. which of the DSOs cost components, do we find the cost associated with a larger EV stock?

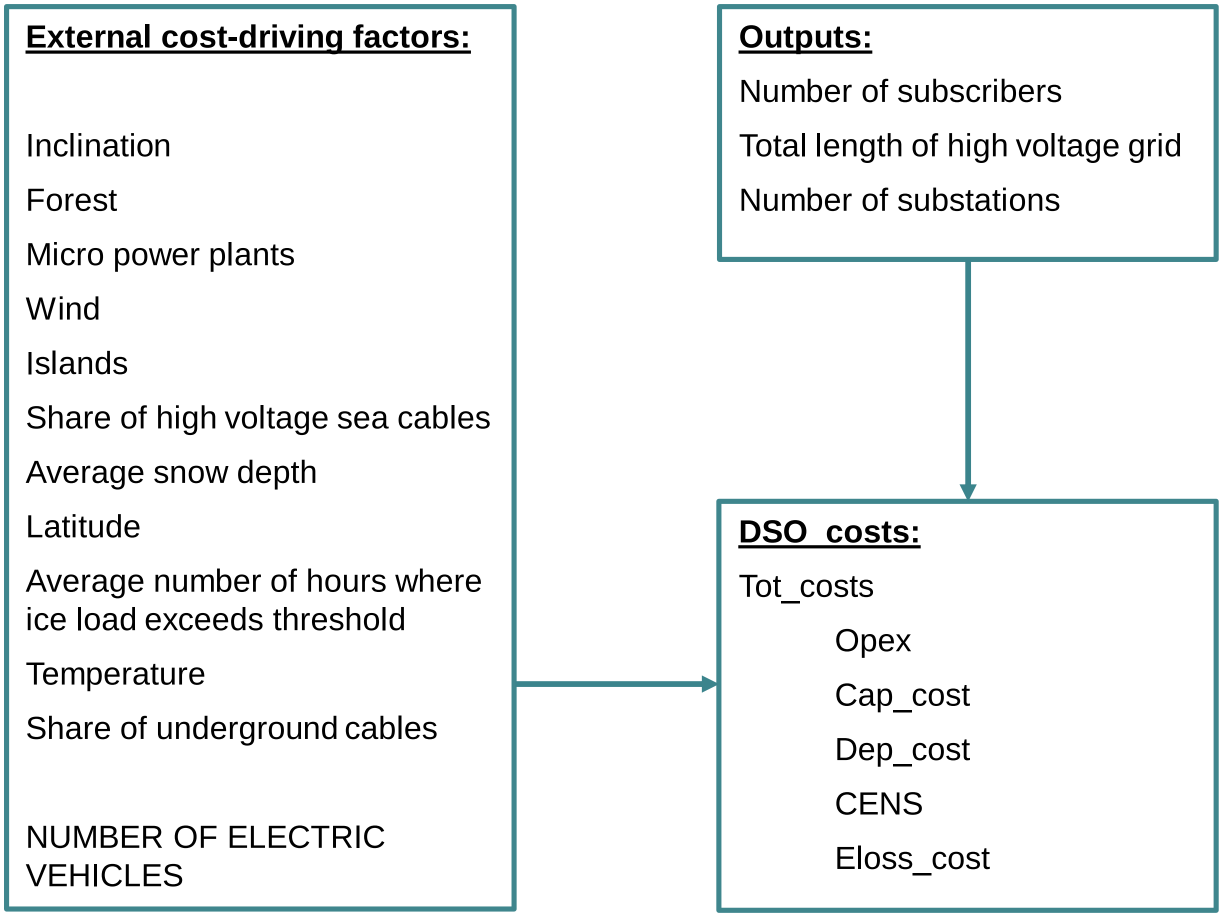
DATA

Panel dataset of 107 DSOs for the years 2008-2017 – 1070 observations

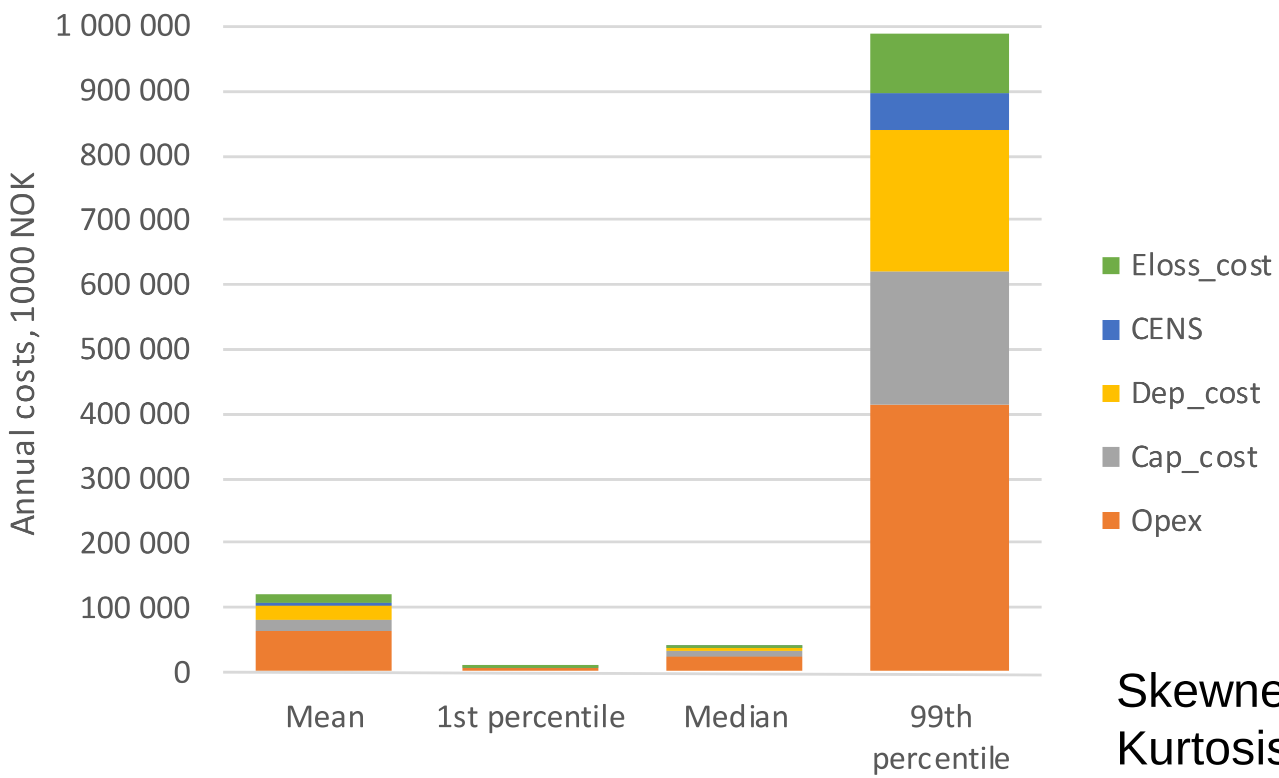
We match and merge together 3 datasets:

1) NVE’s data for DSO costs and outputs applied for regulation
2) NVE’s data for the DSOs legal operational area
3) Statistics Norway’s data over registered cars at municipal level

The variables, and the direction of impacts from outputs and external cost-driving factors to costs



Descriptive statistics: DSO costs



Skewness: 5.05
Kurtosis: 35.39

We transform the variables to log-form:
Skewness: 0.83
Kurtosis: 3.67

METHOD

A fixed effects regression model on a balanced panel

- Avoid issues of unmeasured time-invariant variables that we expect have an effect on both our explanatory variable of interest and the endogenous variable
  - *E.g. temperature, sprawl etc.*
- FE reduces the risk of omitted variable bias, making it more likely that the relationship we infer between EV density and DSO costs to be causal

A priori reasons to believe that EV density can be considered an exogenous regressor

- Even if higher EV density led to higher costs for DSOs and higher grid rent, dramatic price hikes would be needed to make noticeable changes in EV demand.
- Electricity costs make about 15% of the distance-based cost for EVs, and grid rent makes up less than half of the bill before taxes.
- Not certain that the DSO can pass on all of their cost increase to their customers due to regulation.
- In other words, we expect EVs to affect grid costs, and have very little feedback the other way around.

We are left with a few time-variant variables

External cost-driving factors:

~~Inclination~~

~~Forest~~

~~Micro power plants~~

~~Wind~~

~~Islands~~

~~Share of high voltage sea cables~~

~~Average snow depth~~

~~Latitude~~

~~Average number of hours where ice load exceeds threshold~~

~~Temperature~~

~~Share of underground cables~~

NUMBER OF ELECTRIC VEHICLES

Outputs:

Number of subscribers

Total length of high voltage grid

Number of substations

DSO costs:

Tot_costs

- Opex
- Cap_cost
- Dep_cost
- CENS
- Eloss_cost

Model specification

$$\log\_tot_{it} = \alpha_i + \beta_1 \log\_subscribe_{it} + \beta_2 \log\_voltline_{it} + \beta_3 \log\_EV_{it} + \beta_4 \log\_substations_{it} + \beta_5 event_{It} + \beta_6 Year\_Dummy_t + \varepsilon_{it}$$

- Log_tot: Log of total costs
- Log_subscribe: Log of number of subscribers
- Log_voltline: Log of km of high voltage line
- Log_EV: Log of EV stock
- Event: Number of extreme weather events
- Log_substations: Log of number of substations

RESULTS

The effect of EV density on costs seems to be economically significant, but imprecisely estimated

	(1) log_tot	(2) log_tot	(3) log_tot	(4) log_tot	(5) log_tot (removed outliers)
log_subscribe	0.338^{*}	0.222	0.289	0.276	0.250
	(0.192)	(0.247)	(0.243)	(0.245)	(0.254)
log_voltline	0.318^{**}	0.305^{**}	0.293^{**}	0.287^{*}	0.271^{*}
	(0.147)	(0.147)	(0.147)	(0.148)	(0.149)
event	0.007^{***}	0.008^{***}	0.004^{*}	0.004^{*}	0.004
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
log_ev	0.011^{***}	0.007	0.011	0.010	0.007
	(0.004)	(0.006)	(0.007)	(0.007)	(0.007)
year		0.004			
		(0.005)			
log_substation				0.025^{**}	
				(0.012)	
_cons	5.835^{***}	-1.399	6.420^{***}	6.417^{***}	6.873^{***}
	(1.595)	(8.079)	(2.191)	(2.197)	(2.256)
Year dummies	No	No	Yes	Yes	Yes
N	1070	1070	1070	1070	1030
r2_w	0.212	0.214	0.279	0.279	0.289
r2_b	0.982	0.980	0.982	0.982	0.979
r2_o	0.977	0.975	0.977	0.977	0.973
rho	0.948	0.975	0.968	0.968	0.973

Standard errors clustered at DSO level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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The economic significance

- The median number of customers were 7282, they had in total 78 EVs and total costs were 44 mill NOK for 2017
- Let's say the number of EVs doubles, *cetris paribus*
- Model predicts a cost increase of 462 000 NOK (46 200 €) or about 5920 NOK per EV

Heterogeneity test with sample splits along 3 dimensions

	(1) log_tot Lower half customers	(2) log_tot Upper half customers	(3) log_tot Lower half EV density	(4) log_tot Upper half EV density	(5) log_tot Lower half cost per customer	(6) log_tot Upper half costs per customer
log_subscribe	0.336	0.491	0.124	0.638**	0.280	0.490
	(0.315)	(0.361)	(0.304)	(0.263)	(0.270)	(0.377)
log_voltline	0.459***	-0.317	0.490***	-0.009	0.075	0.375**
	(0.139)	(0.351)	(0.160)	(0.240)	(0.288)	(0.142)
event	0.010***	0.001	0.001	0.006*	0.003	0.006
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.004)
log_ev	0.035***	0.003	0.025**	0.002	0.011	0.027**
	(0.010)	(0.009)	(0.011)	(0.010)	(0.009)	(0.011)
_cons	4.828*	8.931**	4.755*	7.849**	8.060***	4.135
	(2.454)	(3.871)	(2.757)	(3.109)	(2.713)	(3.008)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
N	535	535	540	530	540	530
r2_w	0.157	0.094	0.289	0.311	0.251	0.343
r2_b	0.977	0.978	0.933	0.973	0.993	0.972
r2_o	0.974	0.975	0.921	0.966	0.987	0.964
rho	0.957	0.909	0.831	0.986	0.990	0.753

Standard errors clustered at DSO level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

EVs affect cost components positively but statistically insignificantly, with the exception of grid-losses

	(1) log_opex	(2) log_cap	(3) log_cens	(4) log_depres	(5) log_gridloss	(6) log_regulat_assets	(7) log_copaid_assets
log_subscribe	0.338	0.120	0.080	0.146	1.244***	0.120	-1.034
	(0.386)	(0.380)	(1.210)	(0.372)	(0.454)	(0.380)	(1.125)
log_voltline	0.181	0.446**	1.146	0.259	0.594***	0.446**	1.348*
	(0.202)	(0.217)	(0.751)	(0.272)	(0.211)	(0.217)	(0.764)
event	0.006	0.005*	0.007	-0.002	0.000	0.005*	-0.006
	(0.004)	(0.003)	(0.012)	(0.005)	(0.006)	(0.003)	(0.009)
log_ev	0.002	0.014	0.018	0.010	-0.034**	0.014	0.019
	(0.010)	(0.011)	(0.030)	(0.013)	(0.015)	(0.011)	(0.035)
_cons	6.104*	5.177	-0.698	6.018	-6.576*	7.775**	10.752
	(3.311)	(3.399)	(10.190)	(3.976)	(3.878)	(3.399)	(9.774)
N	1070	1070	1070	1070	1070	1070	1068
r2_w	0.134	0.833	0.125	0.507	0.195	0.687	0.543
r2_b	0.962	0.935	0.917	0.965	0.957	0.935	0.049
r2_o	0.951	0.916	0.809	0.942	0.940	0.923	0.076
rho	0.938	0.974	0.350	0.976	0.968	0.974	0.964

Standard errors clustered at DSO level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

DISCUSSION

A few things that have surprised us

- Economically significant, but not statistically significant
- The effect per EV seems to be diminishing as the EV density increases in a DSO's operational area
- A negative, but statistically significant impact on grid-losses

The wide confidence interval and other caveats

- β_3 has a 95% CI of [-0.0028 , 0.0238]
- Would want more precision before including it into calculations for DSO regulation?
- We estimate the relationsship between costs and *registered* EVs
  - *We do not have data on charging behavior*
  - *Costs may accrue eslwhere, e.g., in areas with many cabins*

CONCLUSION

We would not recommend EV density as a variable in the DSO regulation quite yet

- Statistically insignificant, but point estimates fairly large
- The effect per EV seems to be diminishing as the EV density increases
- Cautios optimist's interpretation: A shift from conventional cars to electric cars have social costs. However, as of now the costs are *not* in any statistically significant degree coming in the form of added cost to the local grid.

Thank you for your attention!

For any questions or comments not covered in the following Q&A, you may reach me at pbw@toi.no

I will also be happy to send you a complete working paper when it is finished in the next few months. Just let me know!