Analyzing the Impact of Policies and Macroeconomic Factors on Electric Vehicle Sales

Shang-Chieh Wei

Advisor: Hung-Jen Wang
Department of Economics
National Taiwan University

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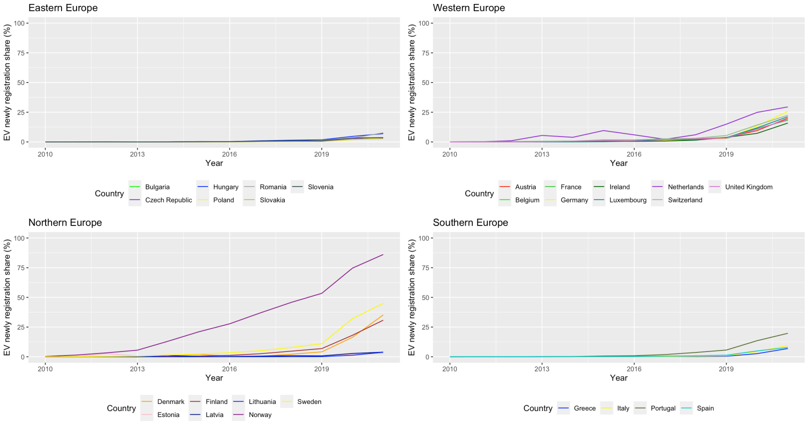
Motivation

- The past decade has witnessed a surge in electric vehicle (EV) sales. In 2022, the global road saw a fleet of 26 million EVs, a fivefold increase from the 2018 count.
- In 2022, Europe emerged as a pivotal player in the global EV market, marking its position as the second-largest market after China.
- Europe accounted for 25% of the global EV sales, showcasing a significant leap in adoption rates.

- Plug-in electric vehicle registrations in 27 European markets (share of total new car registrations from 2010 to 2021)



Motivation

The analysis of the interplay between macroeconomic factors and EV demand becomes increasingly important, especially in industries integral to the EV ecosystem.

- battery and essential minerals
- semiconductor manufacturers
- financial market
- long-term economic planning

Literature Review

- Sierzchula et al. (2014): highlighted the positive influence of financial incentives, charger density, and the presence of EV production facilities
- Plötz et al. (2017): 1000 Euro higher subsidy will increase the PEV sales share by about 16%
- Li et al. (2017): found positive influence of charger density, education level, and population density
- Münzel et al. (2019): found positive influence of financial incentives, especially recurring ones
- Xue et al. (2021): unveiled positive influence of ownership tax benefits, charger density, and household disposable income
- Saether (2022a): emphasized the positive influence of charger density, urbanization, and fuel prices

Motivation

- Existing research examined various aspects of EV adoption.
- The interplay between macroeconomic variables and EV demand has remained relatively unexplored in existing literature.
- This thesis seeks to address this gap by explicitly focusing on the influence of macroeconomic factors on EV sales.

1. Introduction
2. Data and Variables
3. Panel Data Regression Model
4. Panel VAR Model
5. Conclusion

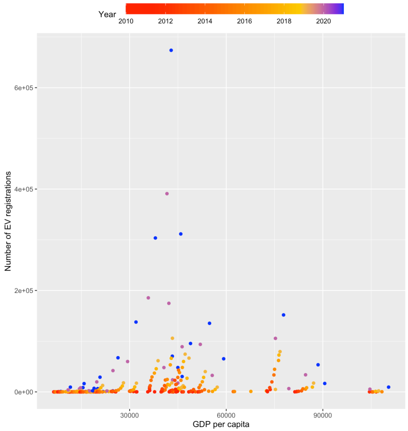
Variables and Sources

Variable	Description	Source
EV registrations	number of EV registration	EAFO
chargers	number of recharging points	EAFO
GDP per capita	GDP per capita (constant 2015 US$)	World Bank
inflation	inflation, consumer prices (annual %)	World Bank
interest rate	3-month interbank rates	OECD.Stat
petrol price	petrol end-user price, USD per liter, 2015	OECD.Stat
electricity price	residential electricity price, USD per kWh, 2015	OECD.Stat

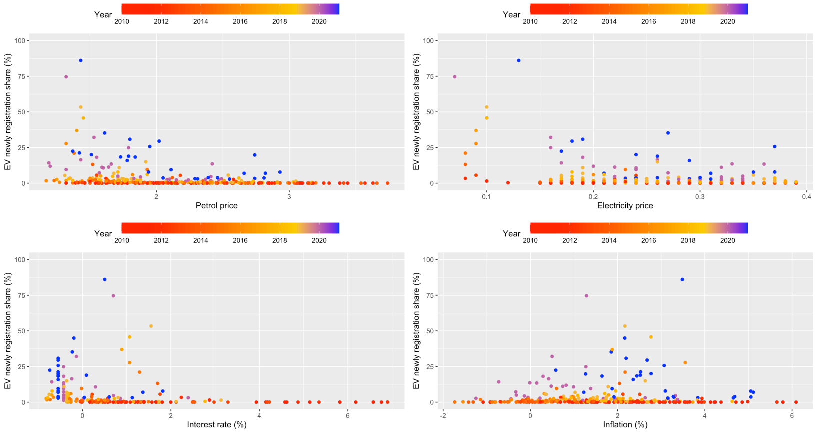
Variables and Sources

Variable	Description	Source
registration tax benefits	whether a country provides registration tax benefits $(=1)$ or not $(=0)$	EAFO, ACEA, and Saether (2022)
ownership tax benefits	whether a country provides ownership tax benefits $(=1)$ or not $(=0)$	EAFO, ACEA, and Saether (2022)
company tax benefits	whether a country provides company tax benefits $(=1)$ or not $(=0)$	EAFO, ACEA, and Saether (2022)
purchase subsidies	whether a country provides purchase subsidies $(=1)$ or not $(=0)$	EAFO, ACEA, and Saether (2022)

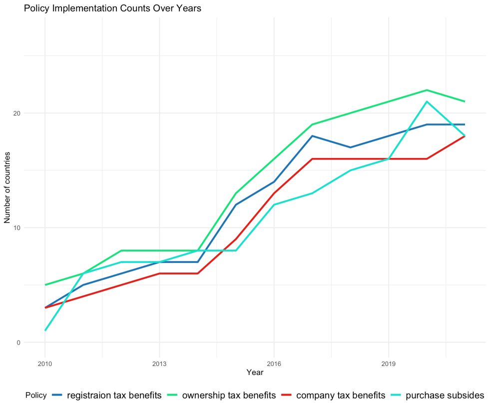
- EV registrations in relation to GDP per capita (left) and number of chargers (right).



- EV registration share (%) in relation to petrol price (top left), electricity price (top right), interest rate (bottom left) and inflation (bottom right).



- Overview of policy implementation in 27 European markets from 2010 to 2021.



Fixed-Effect Model

We estimate the following fixed-effect regression model:

$$Y_{it} = \alpha_i + \beta_1 X_{1,it} + \cdots + \beta_k X_{k,it} + \epsilon_{it}, \tag{1}$$

with $i = 1, \ldots, n$ and $t = 1, ..., T$. The α_i are entity-specific intercepts that represent heterogeneities across entities.

Fixed-Effect Model

In the context of our analysis, Equation (1) can be expressed as:

$$
\begin{aligned}
&\log(\text{EV registrations})_{it} = \\
&\alpha_i + \beta_1 \log(\text{Chargers})_{it} + \beta_2 \Delta \log(\text{GDP per capita})_{it} \\
&+ \beta_3 \text{Inflation}_{it} + \beta_4 \text{Interest rate}_{it} \\
&+ \beta_5 \Delta \log(\text{Petrol price})_{it} + \beta_6 \Delta \log(\text{Electricity price})_{it} \\
&+ \beta_7 \text{Registration tax benefits}_{it} + \beta_8 \text{Ownership tax benefits}_{it} \\
&+ \beta_9 \text{Company tax benefits}_{it} + \beta_{10} \text{Purchase subsidies}_{it} + \epsilon_{it}, \qquad (2)
\end{aligned}
$$

where $\Delta \log(\text{Variable})_{it} = \log(\text{Variable})_{it} - \log(\text{Variable})_{i,t-1}$.

Distributed Lag Model

The general distributed lag model can be expressed as follows:

$$Y_{it} = \alpha_i + \beta_1 X_{i,t} + \beta_2 X_{i,t-1} + \cdots + \beta_{m+1} X_{i,t-m} + \epsilon_{it}, \qquad (3)$$

where the contemporaneous effect of X on Y, β_1, is called the impact effect and the m-period cumulative dynamic causal effect of X on Y is defined as $\beta_1 + \cdots + \beta_{m+1}$.

Unit Root Test

- Unit root: non-stationarity
- Unit root problems: spurious regression
- Solution: differencing or log-differencing

Unit root test

To test for unit roots, one can consider the following regression model:

$$Y_{it} = \rho_i Y_{i,t-1} + \mathbf{z}'_{it}\gamma_i + \epsilon_{it}. \tag{4}$$

We employ the Harris-Tsavalis test (HT test) and the Im-Pesaran-Shin test (IPS test).

Unit Root Test

	HT test statistics			IPS test statistics	
Variables	trend & intercept	intercept	none	trend & intercept	intercept
log(EV registrations)	−5.414***	−7.997***	−3.105***	−3.155***	−2.272***
log(charger)	−2.157**	−8.593***	−5.963***	−2.536***	−2.444***
log(GDP per capita)	−0.529	3.508	−0.448	−2.244	−0.882
inflation	−2.094**	−8.391***	−17.946***	−2.561***	−2.357***
interest rate	2.328	−0.205	−6.221***	−2.223	−2.333***
log(petrol price)	2.518	2.278	−0.445	−2.022	−1.068
log(electricity price)	−0.073	−1.683**	−0.173	−1.712	−1.633

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Panel Data Regression

Model	(1)		(2)	
Variables	Coef.	Std. Err.	Coef.	Std. Err.
$\log(\text{charger})_{it}$	0.381***	0.035	0.442***	0.087
$\log(\text{charger})_{i,t-1}$			0.102*	0.054
$\log(\text{charger})_{i,t-2}$			0.129***	0.043
$\Delta\log(\text{GDP per capita})_{it}$	0.006	0.029	−0.025	0.019
$\Delta\log(\text{GDP per capita})_{i,t-1}$			−0.003	0.035
$\Delta\log(\text{GDP per capita})_{i,t-2}$			0.064**	0.031
inflation_{it}	0.413***	0.080	0.355***	0.084
$\text{inflation}_{i,t-1}$			−0.149	0.090
$\text{inflation}_{i,t-2}$			0.070	0.096
$\text{interest rate}_{it}$	−0.520***	0.119	−0.059	0.202
$\text{interest rate}_{i,t-1}$			0.247	0.335
$\text{interest rate}_{i,t-2}$			−0.435*	0.249

*** p<0.01, ** p<0.05, * p<0.1

Panel Data Regression

Model	(1)		(2)	
Variables	Coef.	Std. Err.	Coef.	Std. Err.
$\Delta \log(\text{petrol price})_{it}$	−0.030**	0.013	−0.002	0.013
$\Delta \log(\text{petrol price})_{i,t-1}$			−0.016	0.014
$\Delta \log(\text{petrol price})_{i,t-2}$			0.036*	0.018
$\Delta \log(\text{electricity price})_{it}$	−0.011	0.007	−0.007	0.008
$\Delta \log(\text{electricity price})_{i,t-1}$			−0.005	0.012
$\Delta \log(\text{electricity price})_{i,t-2}$			−0.002	0.010
ownership tax benefits_{it}	1.023***	0.272	0.597**	0.262
purchase subsidies_{it}	0.764***	0.199	0.394	0.252
company tax benefits_{it}	0.313	0.350	−0.010	0.327
registration tax benefits_{it}	0.281	0.297	−0.042	0.217
constant	3.042***	0.280	2.306***	0.550

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Cumulative Effects

Variables	Coef.	Std. Err.
log(charger)	0.674***	0.080
Δ log(GDP per capita)	0.036	0.061
inflation	0.276**	0.103
interest rate	−0.246*	0.124
Δ log(petrol price)	0.017	0.021
Δ log(electricity price)	−0.014	0.022
ownership tax benefits	0.597**	0.262
purchase subsidies	0.394	0.252
company tax benefits	−0.010	0.327
registration tax benefits	−0.042	0.217
constant	2.306***	0.550

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Panel Data Regression

- A 1% increase in GDP per capita growth rate from 2 years ago results in a 6.373% increase in the current-year EV registrations.
- A 1% increase in interest rate from 2 years ago leads to a 35.27% decrease in EV registration.
- The presence of ownership tax benefits is linked to a substantial increase in EV registrations, approximately 81.67%.
- The findings underscore the durable goods attributes of EVs.

Panel VAR

In general, a k-variate panel VAR of order p model with panel-specific fixed-effects can be represented as follows:

$$\mathbf{Y}_{it} = \alpha_i + \mathbf{A}_1 \mathbf{Y}_{it-1} + \mathbf{A}_2 \mathbf{Y}_{it-2} + \cdots + \mathbf{A}_p \mathbf{Y}_{it-p} + \mathbf{B}\mathbf{X}_{it} + \epsilon_{it}, \tag{5}$$

$$i = 1, 2, \ldots, N; \quad t = 1, 2, \ldots, T_i.$$

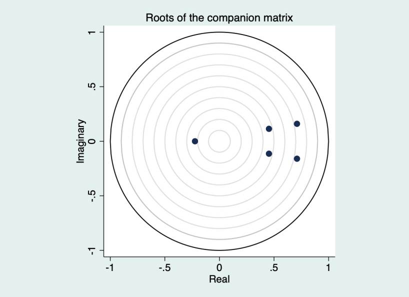
Optimal Lag Order of Panel VAR

The optimal lag order in the panel VAR model is selected to minimize the Moment and Model Selection Criteria (MMSC): $MMSC_{AIC}$, $MMSC_{BIC}$, and $MMSC_{HQIC}$.

Lag	Hansen's J	J p-value	$MMSC_{BIC}$	$MMSC_{AIC}$	$MMSC_{HQIC}$
1	114.630	0.150	−405.220	−85.340	−215.044
2	79.861	0.329	−310.027	−70.139	−167.395
3	52.599	0.374	−207.326	−47.401	−112.238
4	11.035	0.993	−118.928	−38.965	−71.384

Stability Condition of Panel VAR

To perform impulse response analysis, it's essential to establish the stability of the panel VAR model, ensuring that impulse response functions (IRFs) can be reliably calculated.



VMA Format of Panel VAR

If panel VAR model is stable, then it can be represented in an infinite-order vector moving average (VMA) format.

$$\mathbf{Y}_{it} = \boldsymbol{\alpha}_i + \epsilon_{it} + \boldsymbol{\Psi}_1\epsilon_{it-1} + \boldsymbol{\Psi}_2\epsilon_{it-2} + \cdots = \boldsymbol{\alpha}_i + \sum_{h=0}^{\infty} \boldsymbol{\Psi}_h\epsilon_{it-h}, \tag{6}$$

$$\boldsymbol{\Psi}_h = \begin{cases} \mathbf{I}_k & h = 0, \\ \sum_{j=1}^{h} \boldsymbol{\Psi}_{t-j}\mathbf{A}_j & h = 1, 2, \ldots \end{cases}$$

OIRFs

In general, the simple IRFs $\mathbf{\Psi}_h$ have no causal interpretation since there exists contemporaneous correlation among the innovations ϵ_{it}.

A common approach to identify the causal relationship of the shocks of a panel VAR model is to use orthogonal impulse response functions (OIRFs).

OIRFs

- Decompose the variance-covariance matrix of ϵ_{it}, $\boldsymbol{\Sigma}$, by Cholesky decomposition: $\boldsymbol{\Sigma} = \mathbf{P}\mathbf{P}'$.
- $\mathbf{P}$ can be utilized to orthogonalize the error terms: $\boldsymbol{e}_{it} = \mathbf{P}^{-1}\epsilon_{it}$.

$$\mathbf{Y}_{it} = \boldsymbol{\alpha}_i + \sum_{h=0}^{\infty} \boldsymbol{\Psi}_h \epsilon_{it-h} = \boldsymbol{\alpha}_i + \sum_{h=0}^{\infty} \boldsymbol{\Psi}_h \mathbf{P}\mathbf{P}^{-1} \epsilon_{it-h} = \boldsymbol{\alpha}_i + \sum_{h=0}^{\infty} \boldsymbol{\Phi}_h \boldsymbol{e}_{it-h}. \tag{7}$$

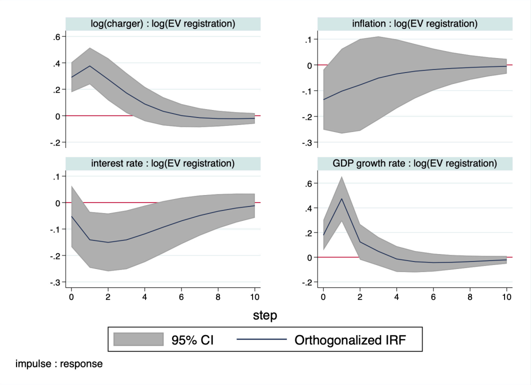
Ordering of Variables

The outcomes of an OIRF could vary depending on the sequence of the variables.

GDP per capita $\rightarrow$ inflation rate $\rightarrow$ interest rate
$\rightarrow$ charger $\rightarrow$ EV registrations

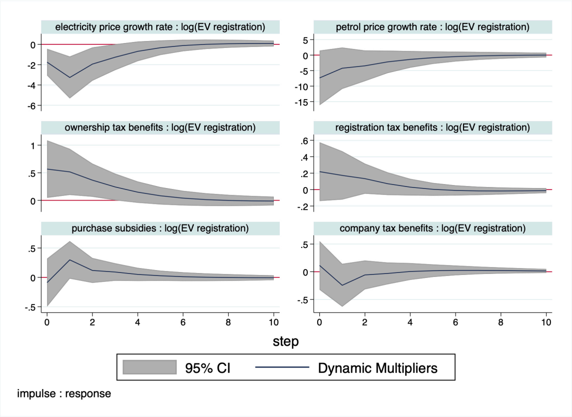
Impulse Response Analysis

- Impulse response analysis of endogenous variables



Impulse Response Analysis

- Impulse response analysis of exogenous variables



Impulse Response Analysis

- GDP: positive impact from the current year to one year later and peaks one year later
- interest rate: negative impact one year later for two years
- electricity prices: negative impact from the current year to two years later and peaks one year later
- ownership tax benefits: positive impact from the current year and endures for two years

Granger Causality Test

The Granger causality test examines whether lags of one variable enter the equation for another variable, i.e.,

$$\begin{aligned} Y_{it} = \alpha_i + \beta_1 Y_{i,t-1} + \beta_2 Y_{i,t-2} + \cdots + \beta_p Y_{i,t-p} \\ + \gamma_1 X_{i,t-1} + \gamma_2 X_{i,t-2} + \cdots + \gamma_p X_{i,t-p} + \epsilon_{it}. \end{aligned} \tag{8}$$

If $\gamma_1 = \gamma_2 = \cdots = \gamma_p = 0$, then X does not Granger cause Y.

Granger Causality Test

Equation	Excluded	Chi-sq	df	p-value
log(charger)	log(EV registration)	0.542	1	0.462
log(EV registration)	log(charger)	20.502***	1	0.000

Null hypothesis: Excluded variable does not Granger cause Equation variable

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Granger Causality Test

- Chargers Granger cause EV registrations but not the other way around

Conclusion

- Our analysis reveals positive lagged effects of GDP per capita and negative lagged effects of interest rates on EV demand.
- A 1% increase in GDP per capita growth rate from two years prior results in a 6.373% increase in current-year EV registrations.
- A 1% increase in the interest rate from two years ago leads to a 35.27% decrease in current-year EV registrations.
- GDP: positive impact from the current year to one year later and peaks one year later
- interest rate: negative impact with time lags.

Thank You