Vertical Integration in EV Fast Charging

IO Lunch Seminar

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Motivation

- The market for EV fast charging is rapidly evolving, and has some interesting quirks:
  - Network effects + economies of scale
  - Prevalence of roaming $\Rightarrow$ most consumers see little price variation $\Rightarrow$ muted price competition
  - Vertically-integrated charging networks (sell charging and provide roaming)
  - Large networks use contracts and volume discounts to ‘lock in’ users
  - Recent regulation mandates that ad-hoc prices and roaming access prices must be the same

So, what’s the big deal?

- Network effects: consumers more likely to prefer large, dense networks
- Economies of scale: cost per station likely lower for large vs. small networks
- *Much* higher utilization of top VI networks allows them to further expand
- Smaller networks - with lower utilization - will likely struggle
- Significant consolidation is likely, with dominant players becoming entrenched and potentially buying out smaller competitors
- How do we regulate this market *now* so that it doesn’t become a problem in the *future*?

Question(s)

- To what extent do network effects combined with price discrimination enhance large, vertically-integrated networks' market power?
- What is the optimal regulation on ad-hoc prices and roaming access fees, given that firms are able to price discriminate?
- Would banning price discrimination help competition and bring down prices, or make users worse off?

Data

1. Real-time, station level charging utilization data for the German fast charging market (11/2023-present day)
2. Charging check-in data from two major sources:
   - &-Charge.com: Charging check-in data from over 16,000 German drivers (with driver ID!)
   - GoingElectric.de: Charging check-in data with charging plan used and vehicle driven (but no driver ID)
3. Comprehensive data on roaming prices in the German market (scraped): for each plan r and network j, I can see the cost to the consumer to charge with plan r on network j

Background

- Charging networks (a.k.a. Charging Point Operators - CPOs)
  - Sell electricity to EV drivers who visit their stations
  - Kind of like gas station brands
  - Set a uniform price for ad-hoc (without a plan) charging in their network
- Roaming providers
  - Intermediary between drivers and CPOs
  - Allows drivers to conveniently charge at any CPO in the provider's roaming plan,
  - Usually have fixed price per kWh (or few tiers)
- Vertically-integrated (VI) CPOs
  - Act as both CPOs as well as roaming providers
  - Often offer multiple plans
  - May also have affiliations with big roaming providers

How charging works

Suppose a consumer has a membership with network A

- In-network charges:
  - Driver navigates to the station, picks a charger, and initiates the charge (through app, chargecard, card reader, etc)
  - Based on the network and plan, the consumer will pay A per kilowatt-hour (kWh) charged
- A consumer can also charge ad-hoc at a station, but the price is usually much higher than the price for members[1]

[1] Per the 2024 Alternative Fuels Infrastructure Regulation (AFIR), all stations must provide ad-hoc charging capabilities

How roaming works

- To charge at network B (covered by a given roaming plan n), consumer navigates to the station and initiates charge using n's app/chargecard
- Consumer pays a per-kWh roaming fee to n (potentially varying based on network)
- In turn, n pays B a pre-determined access/interchange price per kWh
- As of April 2024, this access price must be the same as B's ad-hoc charging price[2]

[2] Per the 2024 Alternative Fuels Infrastructure Regulation (AFIR)

Major VI CPOs

- EnBW:
  - Large national utility with largest network
  - Offers multiple widely-used roaming plans with volume discounts
  - Used to partner with large roaming provider (ADAC)
- IONITY:
  - Joint venture of automakers (VW, BMW, Mercedes, Hyundai, etc.)
  - Primarily located on Autobahn (motorway)
  - Offers multiple plans with volume discounts
  - Each automaker's roaming plans offer preferential prices at IONITY stations
- Aral Pulse
  - Owned by Aral (German subsidiary of BP), operates a large charging network
  - Offers roaming plan and also partners with large roaming provider (ADAC)
  - Also partners with automakers' roaming plans, to a lesser extent
- There are other VI CPOs, but they are not as widely utilized (EWE, Shell Recharge, E.ON)

Major roaming providers

- ADAC e-Charge (partner with Aral, prev. EnBW)
  - ADAC is a large motorist association with basic membership of €54/year (€4.5/month)
  - One of the largest, most popular roaming plans
  - Offers discounted rate at partner network and flat price for other networks
- Maingau Autostrom
  - Maingau is a large national utility which offers a free roaming plan
  - Offers charging at flat rate (with exception of a few major networks, including EnBW and Aral)
  - Discount to their own energy consumers
- Automakers (VW, Hyundai, BMW, etc.)
  - Offer a menu of plans to drivers of their vehicles, often with volume discounts and preferential pricing for IONITY
  - Consumers get 1 year free subscription to higher tier plan with vehicle purchase

CPO classification

- Throughout the rest of the presentation, I'll refer to CPOs with three major classifications:
  - Top VI: CPOs that offer roaming, have multiple plans, and/or partner with other major roaming providers (EnBW, Aral Pulse, and Ionity)
  - Other VI: CPOs that offer roaming/multiple plans but aren't as widely used
  - Non VI: CPOs that don't provide roaming
- I've also included a table of the top 10 networks (Table)
- I have color coded the Top VI networks as red in the presentation to help contrast between them and other networks
- Also, roaming coverage of top networks is almost uniformly complete (Coverage)

Plan example: EnBW

- EnBW has three tiers:
  1. S: €0.59/kWh at EnBW (€0/month)
  2. M: €0.49/kWh at EnBW (€5.99/month)
  3. L: €0.39/kWh at EnBW (€17.99/month)
- Roaming cost is same across plans and varies from €0.59-€0.89/kWh at rival networks
- Best plan based on number of monthly charges at EnBW stations:
  - 0-2 charging events: S
  - 2-4 charging events: M
  - 4+ charging events: L

Pricing

- I tabulate the ad-hoc rate, within-network rate, and roaming prices for a selection of the top roaming plans/VI networks Price table
- I also include a similar table broken down by network (By network)
- Main takeaways:
  1. Ad-hoc charging prices are very high
  2. VI CPOs provide discounts for their own network and charge more for roaming
  3. In exchange for a monthly fee, CPOs offer an even bigger discount (and sometimes cheaper roaming)
- After AFIR came into effect in 2024, roaming access/interchange fees must be the same as ad-hoc prices
  - This was associated with a sizable increase in roaming prices across multiple major plans (Table)

Fact #1: Network effects

- As we would expect, bigger networks have larger market share
- However, the largest networks with major roaming plans get an outsized share of charging (Plot)
- The same holds at the local level, with large VI networks getting on outsized share and non-VI networks underperforming (Plot)
- This makes intuitive sense:
  - Denser network $\Rightarrow$ more likely to choose plan $\Rightarrow$ use network more (because of discount)
- These plots alone don't tell us whether this is from quality/prices or from network effects/VI. However, they are consistent with what we would expect

Fact #2: Higher utilization

- Large VI CPOs have much higher station utilization compared with other networks
- The mean number of charges per station for each VI status: (Table)
  - Top VI: 23.59/day
  - Other VI: 9.65/day
  - Non-VI: 8.24/day
- Top VI networks also perform well even when other competitors are present (Table)

Hypothetical annual revenue

- That's a huge difference in annual gross profit per station:[3]
  - Top VI: €129,155/yr
  - Other VI: €52,833/yr
  - Non-VI: €45,114/yr
- Considering the massive cost of constructing + maintaining fast chargers (anywhere from €60,000-€160,000 per charger, with multiple per station), these differences add up!

[3] Assuming gross margin of €0.5/kWh and 30 kWh charged per session

Fact #3: Plan usage (GoingElectric.de Data)

- Plan membership and roaming is prevalent, with around 80% of charging done with either a VI CPO or roaming provider's plan in recent years (post 2022) (Table)
- Roaming share has increased over time, especially from large VI providers (Plot)
- For large VI networks, large share of charging comes from either own plan or roaming partner's plan (EnBW, Ionity, Aral)
- For plans with preferential rate/discount within network, share of in-network charging is higher (EnBW, Ionity, ADAC (EnBW))

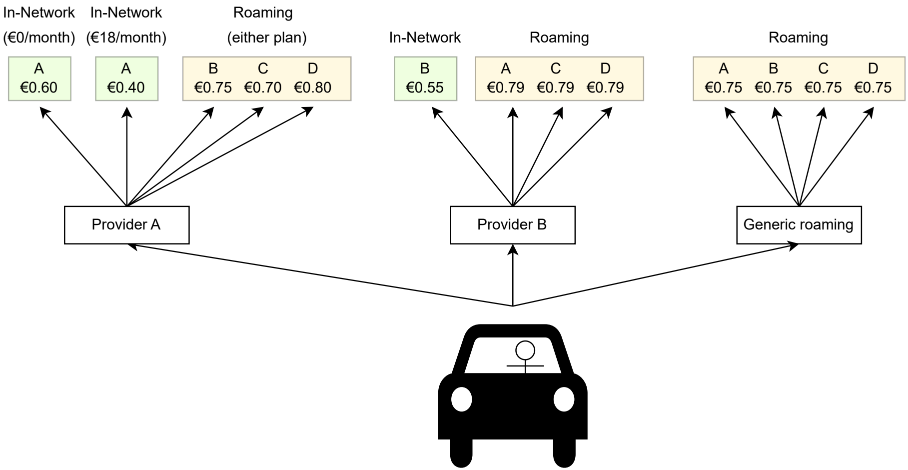
Model overview

- I model the market for EV fast charging along the motorway
- I allow consumers to have heterogeneous preferences and valuations of public charging
- Consumers make a choice between roaming plans which give them access to networks at different prices
- On the supply side, I model competition between charging networks given the presence of roaming plans
- I also model competition between roaming providers, including vertically integrated charging networks which offer roaming services

Model timing

1. CPOs set prices and bargain with roaming providers over inclusion in their network
2. Roaming plans and vertically-integrated CPOs set roaming prices for each plan
3. At the beginning of the month, consumers make a choice between the different roaming plans available to them
4. Then, during the month, consumers realize their idiosyncratic shocks and make the choice of where to charge, given the prices they face

Consumer's choice



Consumer primitives

Consider a station l in network j which is included in roaming plan n

- Observables:
  - Ω_n: set of charging networks included in roaming plan n
  - z_l: location of station l
  - x_l: characteristics of station l
  - p_{nj}: price of plan n consumer charging at station l (which is in network j)
- Parameters (to be estimated):
  - β: consumer's preference for station characteristics
  - λ: consumer's preference for location proximity
  - α: consumer's price sensitivity

Consumer heterogeneity

- I allow consumers to have heterogeneous charging preferences:
- Each consumer is indexed by type $\theta_i = (l_i, \sigma_i, v_i)$
  - l_i is the ‘preferred’ charging location of consumer i
  - σ_i represents the heterogeneity in consumers’ taste for charging stations (i.e., the variance of their idiosyncratic TIEV shock)
  - v_i represents the heterogeneity in consumers’ utility from the outside option (e.g. charging at home or work)
- Each consumer has q potential charging choice occasions (say, 30 per month); the outside option is to not use public charging

Charging event utility

- The utility of consumer i of type θ_i charging at station l in network j is given by

$$u_{ilt}(\boldsymbol{p}, \Omega_n, \theta) = x_l\beta - \lambda|l_i - z_l| - \alpha p_{nj} + \sigma_i\varepsilon_{ilt}$$

- x_l is a vector of station characteristics, z_l is the station's location, p_{nj} is the price of charging at network j given consumer's plan n

$$u_{i0t}(\theta) = v_i + \sigma_i\varepsilon_{i0t}$$

Value of roaming plan

- The consumer's expected value from a given charging event conditional on having plan n is given by the inclusive value formula:

$$\bar{u}_n(\boldsymbol{p}, \Omega_n, \theta) = \log\left(\exp(v_i/\sigma_i) + \sum_{l \in \Omega_n} \exp((x_l\beta - \lambda|l_i - z_l| - \alpha p_{nj})/\sigma_i)\right) + \gamma$$

- Assuming each consumer has q potential charging events, their optimal plan will be the solution to the following:

$$\max_n\{q\bar{u}_n(\boldsymbol{p}, \Omega_n, \theta) - \alpha r_n + \varepsilon_n\}$$

Plan membership and demand

- Share of type θ_i consumers on plan n, given set of roaming networks $\Omega = (\Omega_n, \Omega_{-n})$:

$$\mu_n(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta) = \frac{\exp(q\bar{u}_n(\boldsymbol{p}_n, \Omega_n, \theta))}{\sum_j \exp(q\bar{u}_j(\boldsymbol{p}_j, \Omega_j, \theta))}\mu(\theta)$$

- Probability of type θ_i consumers on plan n picking station l:

$$d_{nlt}(\boldsymbol{p}, \Omega_n, \theta) = \frac{\exp((x_l\beta - \lambda|l_i - z_l| - \alpha p_{nj})/\sigma_i)}{\exp(v_i/\sigma_i) + \sum_{k\in\Omega_n} \exp((x_k\beta - \lambda|l_i - z_k| - \alpha p_{nk})/\sigma_i)}$$

- Total demand for station l from type θ consumers on roaming plan n:

$$D_{nlt}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta) = \mu_n(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta) d_{nlt}(\boldsymbol{p}, \Omega_n, \theta) q$$

Supply-side notation cheat sheet

- J : the set of networks
- N: set of roaming plans
- A: a representative VI CPO
- j: representative non-VI CPO
- n: representative roaming plan
- Ω_n: set of networks in roaming plan n
- Ω_{-n}: vector of all roaming plans except for n

Prices and demand

- $\boldsymbol{p}$: industry price vector
- p_j: ad-hoc (without a contract) charging price at network j
- p_{nj}: price for user of plan n to charge at network j
- D_{nj}: demand for network j from members of plan n
- D_{jj}^{Ad-hoc}: ad-hoc (without a contract/plan) demand for network j
- c: marginal cost (I assume these are common across all networks)

Choice variables

- A vertically-integrated CPO A chooses:
  - Ad-hoc charging price/roaming access fee (p_A)
    - Note: when external users roam, their roaming network must pay p_A
    - Setting the ad-hoc price also determines the roaming access price
  - Roaming plan coverage (Ω_A)
  - Roaming plan prices:
    - Plan fee (r_A)
    - In-network charging cost (p_{AA})
    - Out-of-network roaming cost (p_{Aj}) for each rival network $j \in \Omega_A$
- Non-VI networks only choose ad-hoc price p_j
- Standalone roaming plans (n) only choose p_n and roaming coverage Ω_n

VI provider (A) profits

$$\Pi_A(\boldsymbol{p}, \boldsymbol{\tau}, \Omega_A, \Omega_r) = \underbrace{\sum_{\theta \in \Theta} D_{AA}^{Ad-hoc}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_A - c)}_{\text{Ad-hoc profits}}$$

$$+ \underbrace{\mu_n(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta) r_A}_{\text{Plan fees}} + \underbrace{\sum_{\theta \in \Theta} D_{AA}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_{AA} - c)}_{\text{Plan users charging in-network}}$$

$$+ \underbrace{\sum_{\theta \in \Theta} \sum_{j \in J} D_{Aj}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_{Aj} - p_j)}_{\text{Plan users roaming on other networks}}$$

$$+ \underbrace{\sum_{\theta \in \Theta} \sum_{n \neq A} D_{nA}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)(p_A - c)}_{\text{External roaming (from other providers)}}$$

Non-VI network (j) profits

$$\Pi_j(\boldsymbol{p}, \boldsymbol{\tau}, \Omega) = \underbrace{\sum_{\theta \in \Theta} D_{jj}^{Ad-hoc}(\boldsymbol{p}, \Omega, \theta)(p_j - c)}_{\text{Profits from ad-hoc sales}}$$

$$+ \underbrace{\sum_{n \in N} \sum_{\theta \in \Theta} D_{nj}(\boldsymbol{p}, \Omega_n, \Omega_{-n}\theta)(p_j - c)}_{\text{Profits from sales through roaming networks}}$$

- Note that by regulation, the roaming access price must be the ad-hoc price set by the network

Roaming provider (n) profits

$$\Pi_r(\boldsymbol{p}, \boldsymbol{\tau}, \Omega_n, \Omega_{-n}) = \underbrace{\sum_{\theta \in \Theta} \sum_{j \in J} D_{rj}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)(p_n - p_j)}_{\text{Profit from roaming sales}}$$

Price setting FOCs

- VI Firms:
  - Ad-hoc price FOC
  - In-network price FOC
  - Roaming price FOC
- Non-VI firms:
  - Ad-hoc price FOC
- Roaming providers:
  - Roaming price FOC

Intuition: VI in-network prices

- Lowering my in-network price:
  1. Increases in-network charging from my plan's consumers
  2. Decreases my consumers' charging on rival networks (through my roaming plan)
  3. Increases the number of users on my plan
  4. Decreases the amount of ad-hoc charging
- The overall effect depends on the price elasticity of my consumers

Intuition: VI ad-hoc prices

- Raising my ad-hoc price:
  1. Directly increases my profits from roaming and ad-hoc charging
  2. Decreases the quantity of ad-hoc charging
  3. Increases enrollment in my plan
  4. Potentially changes external roaming volume (if my increase raises the overall cost of roaming)
- The overall effect depends on the price elasticity of consumers in vs outside my plan

Intuition: VI roaming prices

- Raising the price to roam on rival networks:
  1. Increases charging at my network from my plan's consumers
  2. Decreases roaming on the rival network
  3. Potentially decreases the number of users on my plan
  4. Potentially causes some ad-hoc + roaming charging from people who left my plan
- The overall effect depends on the price elasticity of my own consumers

Non-VI intuition

- Raising my own ad-hoc price
  - Will increase the margin I get from roaming and ad-hoc charging
  - Will decrease the amount of ad-hoc charging
  - Will potentially change demand from roaming (if my price increase is passed through and roaming price changes)
- The extent to which any of these effects dominates depends on consumers' price elasticity and the type of users who roam

Bargaining over roaming inclusion

- By EU law (as of April 2024), CPOs cannot discriminate in the price they charge for ad-hoc users vs. roaming access
- By setting the ad-hoc price, CPOs effectively make a take-it-or-leave-it offer to roaming providers
- The roaming provider then decides whether to include the network on its platform
- Some intuition:
  - Roaming plans don't want to exclude large, popular networks
  - VI CPOs can tolerate higher access prices, as they may want to raise roaming costs anyway to get more in-network charging

Equilibrium conditions

- Predicted network market shares in each market match observed shares
- Charging behavior within each plan is consistent with consumer optimality
- Charging network and roaming prices must be consistent with profit maximization (solving firms' FOC given demand functions)
- Roaming inclusion must satisfy individual optimality for each roaming provider

Estimation/identification

- Identifying price sensitivity:
  1. Variation in choice set + station-level usage data
  2. Substitution patterns within each plan
  3. Price changes over time
  4. Plan changes (e.g. ADAC replacing EnBW with Aral)
- Preferences for station characteristics/location:
  1. Identified from station-level usage data
  2. &-Charge.com panel lets me see individual's choices over time, so I can see their 'ideal' location and preferred places to charge
- Unobserved heterogeneity
  — &-Charge.com panel tells me how frequently consumers charge, how dispersed their charging trips are, and which networks they choose
  — Do they make different choice when they are farther from 'home'? If their usual network is not available nearby?

Estimation (supply side)

- I see plan details and prices for all major networks and roaming plans
- Together with the demand estimates and predicted plan membership from the model, I can plug these into the FOC
- Use moments derived from plan usage data to help validate predicted memberships and utilization patterns

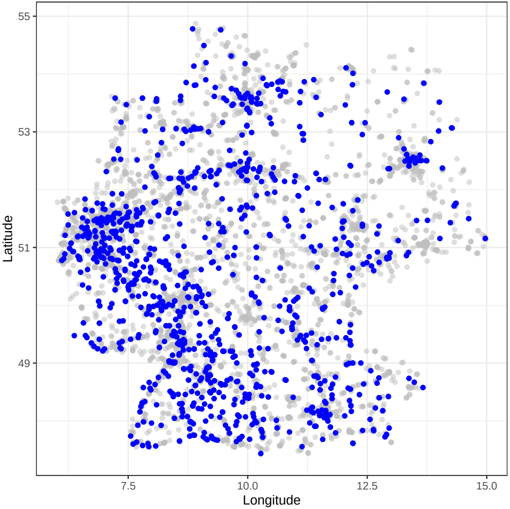
Top CPO table back

Network	Type	Roaming	Vol. discount	Mkt. share	VI Level
EnBW	Utility	✓	✓	0.24	Top VI
IONITY	Auto	✓[4]	✓	0.13	Top VI
Aral Pulse	Gas	✓	✓[5]	0.12	Top VI
Allego	Pure play	✗	✗	0.06	Non-VI
E.ON	Utility	✓	✓	0.05	Other VI
EWE	Utility	✓	✗	0.05	Other VI
Shell Recharge	Gas	✓	✓	0.04	Other VI
Fastned	Pure play	✗	✓	0.03	Non-VI
TotalEnergies	Gas	✗	✗	0.03	Non-VI
Pfalzwerke	Utility	✗	✗	0.02	Non-VI

[4] Technically, Ionity doesn't itself offer roaming, but each automaker in the joint venture offers roaming plans which give preferential rates at IONITY

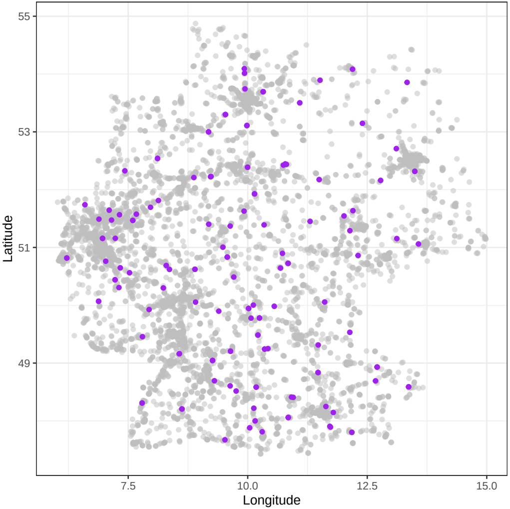
[5] Volume discount through ADAC e-Charge €54/year (€4.5/month)

Network maps



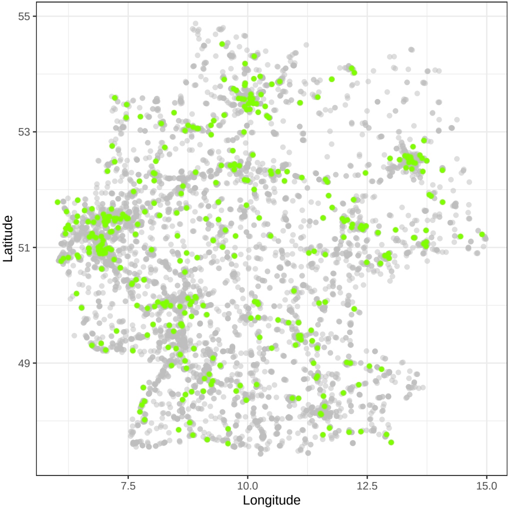
EnBW

Network maps



IONITY

Network maps



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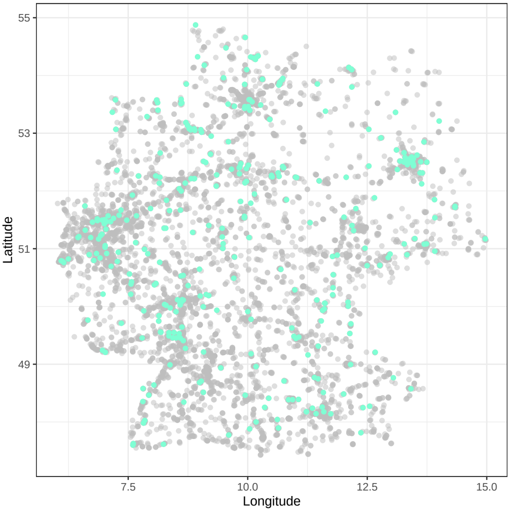
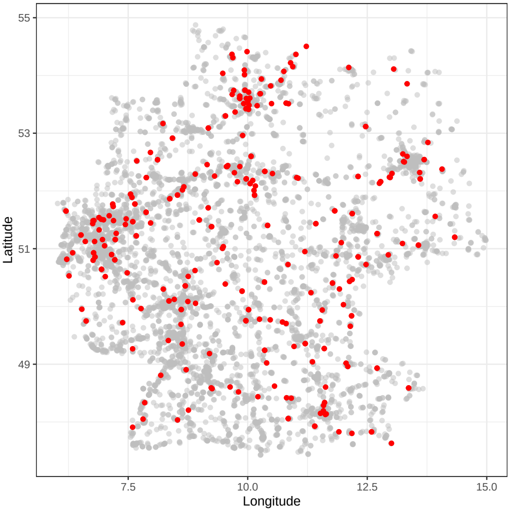


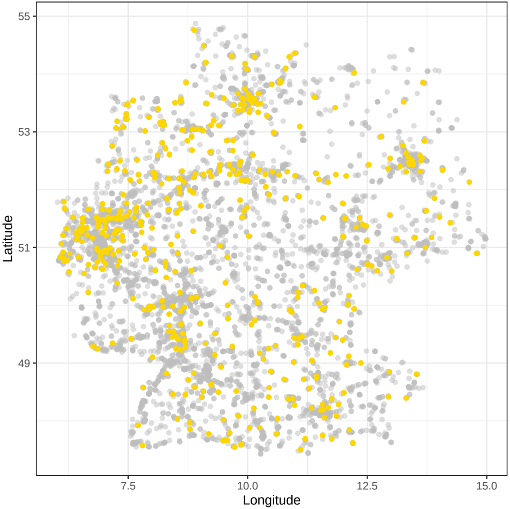
Allego

Network maps



E.ON

Network maps



EWE Go

Top 10 networks (within 1km of motorway)

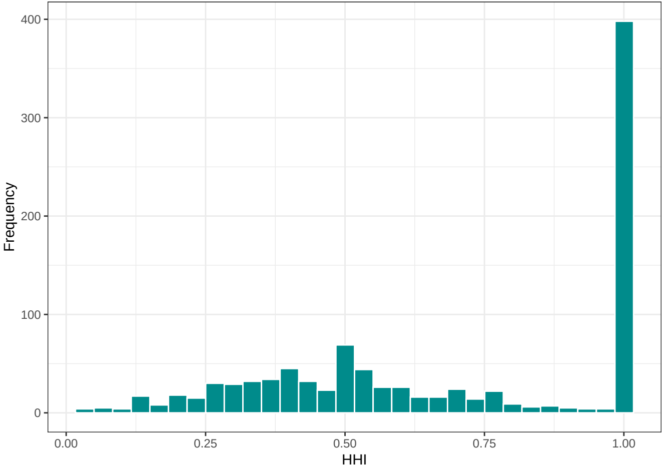
Network	Stations	Share
EnBW (Power)	465	0.24
IONITY (Automaker)	133	0.13
Aral (BP) Pulse (Gas)	194	0.12
Allego (Pure Play)	219	0.06
E.ON (Power)	233	0.05
EWE (Power)	208	0.05
Shell Recharge (Gas)	128	0.04
Fastned (Pure Play)	33	0.03
TotalEnergies (Gas)	70	0.03
Pfalzwerke (Power)	107	0.02
Other	1255	0.21

Stations per market: summary stats

	Min	Q1	Median	Q3	Max
Stations	1.00	1.00	2.00	3.00	47.00
Networks	1.00	1.00	2.00	3.00	19.00
Stations/Net	1.00	1.00	1.00	1.00	3.00

Here, I'm defining a market as a city. This is a relatively narrow market definition, as there may be numerous cities along a highway segment. However, this is intended to capture the idea that whenever you need to charge, you may not have the flexibility to drive 25 more miles

HHI histogram (A hhistogram, if you will)



Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.03	0.43	0.68	0.69	1.00	1.00

Mean local market share

Network	Mean share	Mean charges/stat
IONITY	0.64	5383.02
EnBW	0.62	2749.33
Fastned	0.61	5302.79
Aral Pulse	0.55	3397.19
E.ON	0.47	1236.79
TotalEnergies	0.46	2095.49
Shell Recharge	0.36	1785.34
Allego	0.34	1374.18
Pfalzwerke	0.33	1163.63
EWE	0.32	1309.17

Found market share of each network by city, then found the mean share across all cities by network. Big caveat: Biased upwards towards 1 since around 45% of markets have only one network Part of this is driven by fact that smaller markets may have few (or only one) stations, leading to high share of the present network

Roaming coverage of top 10 networks back

Roaming plan	Network									
	EnBW	Aral	Ionity	Allego	EWE	E.ON	Shell	Fastned	TotalEnergies	Pfalzwerke
EnBW	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Maingau	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ADAC (w/ Aral)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗[6]
Aral	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
VW (Ionity)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EWE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
E.ON	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Shell	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

- Main takeaway is that each roaming plan covers almost all of the major networks (plus many others)

[6] This feels personal

Price table Back

	Roaming plan/provider									
	EnBW		Aral			VW (Ionity)			E.ON	
	S	L	Aral	ADAC	Maingau	Free	Plus	EWE	Flex	More
Ad-hoc	0.87	0.87	0.79	-	-	0.69[7]	0.69	0.79	0.80	0.80
Own[8]	0.59	0.39	0.61	0.57	-	0.73	0.50	0.52	0.62	0.55
Roaming	0.59-0.89[9]	0.59-0.89	0.79	0.75	0.69-0.79	0.93	0.73	0.62	0.79	0.71
Fee (€)	0	17.99	0	4.5	0	0	15.99	0	0	6.99

[7] At Ionity
[8] Own/partner network
[9] Average price is €0.74/kWh, but top networks are mostly $\geq$ €0.79

Price table by network Back

			Roaming plan/provider						
			EnBW		Aral			VW (Ionity)	
Network	Ad-Hoc	w/ Acct	S	L	Aral	ADAC	Maingau	Free	Plus
EnBW	0.87	0.59	0.59	0.39	0.79	0.75	0.79	0.93	0.63
Aral	0.79	0.61	0.79	0.79	0.61	0.57	0.79	0.93	0.50
IONITY	0.69	0.69	0.74	0.74	0.79	0.75	0.69	0.73	0.50
Allego	0.73	0.73	0.84	0.84	0.79	0.75	0.79	0.93	0.63
E.ON	0.80	0.61	0.79	0.79	0.79	0.75	0.79	0.93	0.63
EWE	0.79	0.51	0.69	0.69	0.79	0.75	0.79	0.93	0.63
Shell	0.79	0.64	0.74	0.74	0.79	0.75	0.69	0.93	0.63
Fastned	0.73	0.73	0.74	0.74	0.79	0.75	0.69	0.93	0.63
TotalE.	0.79	0.79	0.89	0.89	0.79	0.75	0.69	0.93	0.63
Pfalz.	0.79	0.79	0.74	0.74	-	-	0.69	0.93	0.63
Fee (€)	-	-	0	17.99	0	4.50	0	0	15.99

Blue: own network; Orange: partner network

Selected roaming prices (€/kWh): pre and post AFIR

back

	Roaming plan			
	EnBW S	EnBW L	Maingau	ADAC[10]
Pre:	0.65	0.5	0.64	0.60
Post:	0.59-0.89[11]	0.59-0.89	0.69-0.79[12]	0.75
Median post:	0.75	0.75	0.69	0.75

- Once the AFIR mandated that CPOs cannot separate ad-hoc charging prices from roaming access prices, the price of roaming across a variety of plans increased significantly over the following months
- Obviously, there's other potential explanations[13], but it's a pretty stark shift

[10] Changed partner from EnBW to Aral

[11] Median for either plan around 0.75

[12] Expensive/popular providers 0.79, others are 0.69

[13] However, electricity prices were mostly stable/decreasing

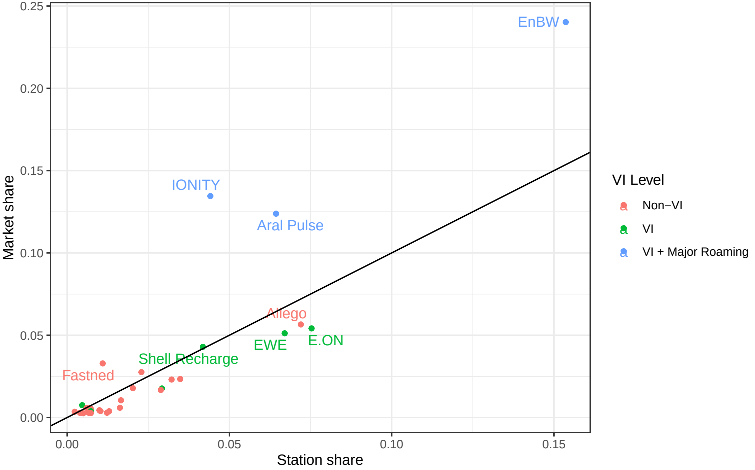
Ad-hoc and mean/median roaming price by network

Network	Ad-Hoc	Mean	Median	SD
EWE Go	0.52	0.75	0.74	0.12
TotalEnergies (HPC)	0.79	0.78	0.79	0.10
Fastned	0.69	0.72	0.72	0.09
IONITY	0.69	0.75	0.75	0.13
allego	0.73	0.76	0.77	0.12
Pfalzwerke	0.79	0.76	0.75	0.10
Shell Recharge	0.79	0.76	0.74	0.12
Aral/BP	0.79	0.77	0.79	0.13
E.ON	0.80	0.77	0.79	0.11
EnBW	0.87	0.76	0.75	0.14

- First column contains the ad-hoc price; remaining three columns contain the mean, median, and SD of roaming prices at each network (all in €/kWh)
- Sorted by ad-hoc price in ascending order

Market share vs. station share[14]

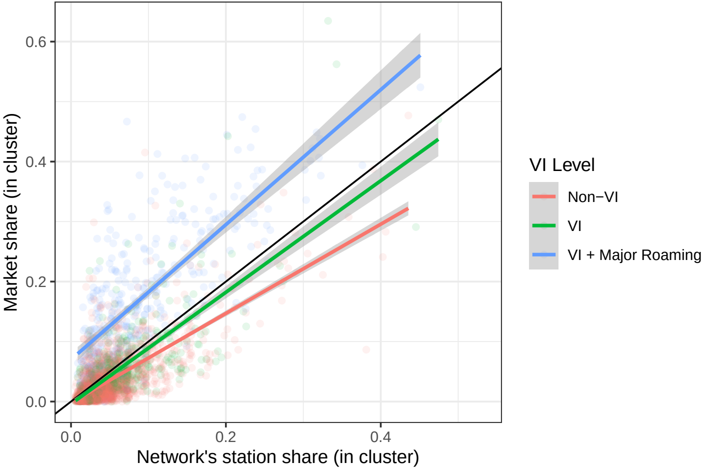
Back



[14] Plotted with 45-degree line

Market share vs. station share, cluster-level Back

- Use k-means clustering to divide the country into 200 clusters and repeat the analysis[15]



[15] Median 41 stations and 17 networks in each cluster

Daily charges per station, by VI status back

VI Level	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Top VI	0.00	10.00	19.00	23.59	33.00	192.00
Other VI	0.00	3.00	7.00	9.65	12.00	370.00
Non-VI	0.00	1.00	5.00	8.24	11.00	244.00

- I compute the summary statistics for daily charges per station for each VI level (Top VI, Other VI, and Non-VI)
- The following slide contains the breakdown by individual network

Daily charges per station, by network

network	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
IONITY	0.00	22.00	36.00	37.43	50.00	162.00
Fastned	0.00	16.00	27.00	35.12	46.00	161.00
Aral Pulse	0.00	10.00	19.00	23.90	32.00	192.00
EnBW	0.00	8.00	16.00	19.44	26.00	142.00
TotalEnergies	0.00	3.25	11.00	15.42	22.00	139.00
Shell Recharge	0.00	3.00	8.00	12.89	16.00	218.00
Allego	0.00	2.00	6.00	9.64	13.00	131.00
EWE	0.00	4.00	8.00	9.38	13.00	83.00
E.ON	0.00	2.00	6.00	8.68	12.00	123.00
Pfalzwerke	0.00	3.00	6.00	8.26	11.00	79.00

Daily charges per port, by network

network	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
IONITY	0.00	3.75	6.50	7.05	9.75	40.50
Fastned	0.00	2.33	3.80	4.22	6.00	22.17
EWE	0.00	1.50	3.00	3.75	5.50	41.50
EnBW	0.00	1.50	2.88	3.25	4.50	22.67
E.ON	0.00	1.00	2.50	3.18	5.00	45.00
Shell Recharge	0.00	1.00	2.25	2.93	4.00	67.00
Aral Pulse	0.00	1.50	2.56	2.90	3.86	23.50
TotalEnergies	0.00	0.88	2.10	2.80	4.00	28.00
Allego	0.00	0.62	1.62	2.13	3.00	21.83
Pfalzwerke	0.00	0.67	1.33	1.60	2.33	12.67

Local market share by rival count and VI level back

	# of rival networks			
VI Level	1	2	3	4
Top VI	0.62	0.49	0.37	0.32
Other VI	0.46	0.28	0.20	0.15
Non-VI	0.44	0.26	0.19	0.14

- I plot the average local market share across all stations for each VI type
- The columns correspond to the number of competitors in the given market (city)

Market share by rival count and network

	# of rival networks			
Network	1	2	3	4
EnBW	0.64	0.53	0.38	0.49
IONITY	0.76	0.63	0.52	0.46
Aral Pulse	0.66	0.44	0.47	0.26
Allego	0.49	0.26	0.18	0.11
E.ON	0.44	0.22	0.17	0.20
EWE	0.38	0.25	0.21	0.22
Shell Recharge	0.58	0.38	0.16	0.27
Fastned	0.82	0.56	0.38	0.31
TotalEnergies	0.46	0.33	0.44	0.07
Pfalzwerke	0.40	0.44	0.27	0.17

- Same as previous slide, but broken down by network

Network differentiation?

- Most use similar (or same) hardware, with most sourcing from a select few manufacturers[16]
- Companies may differ in their ability/willingness to maintain chargers and respond to issues
- Speed and quality are correlated with price, to an extent
- Reliability may differ across networks
- However, my sense is that the biggest differentiating factors are network breadth and density: can I usually find this network's stations whereever I go?

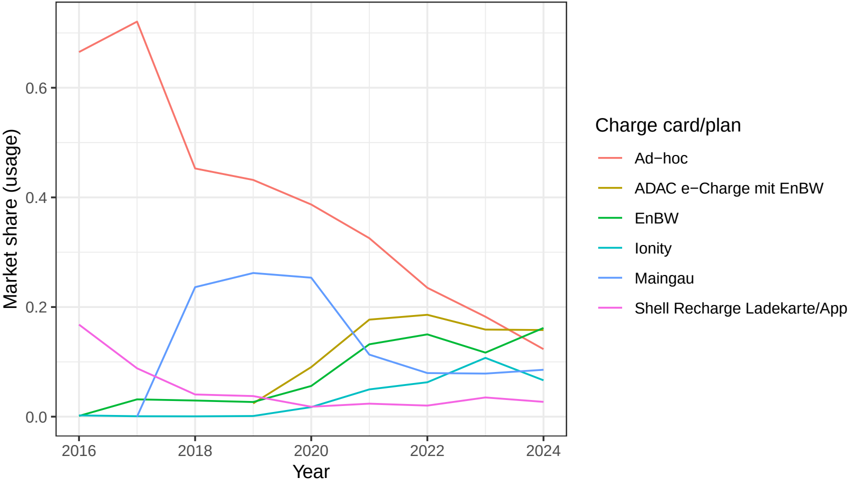
[16] Alpitronic, ABB, EKO Energetyka, or Tritium

Charger hardware similarity example

Aggregate plan usage (post 2022) back

Plan	Usage share
Ad-Hoc	0.20
ADAC e-Charge mit EnBW	0.17
EnBW	0.14
Maingau	0.08
Ionity	0.08
Shell Recharge Ladekarte/App	0.03
EWE Go App / Ladetarif	0.02
E.ON	0.01
Other	0.27

Roaming plan/ad-hoc shares over time back



- Only top plans/payment options plotted for clarity

Breakdown by network (EnBW) back

- Share of charging done at EnBW by each plan provider/group
- Note that ADAC used to partner with EnBW until late 2024, which is why the ADAC is so high here

Plan	Share of net
EnBW	0.46
ADAC e-Charge mit EnBW	0.33
Other	0.15
Ionity	0.02
Ad-hoc	0.02
MAINGAU Autostrom	0.01

Breakdown by network (IONITY) back

Plan	Share of net
Ionity	0.57
Other	0.30
Ad-hoc	0.08
MAINGAU Autostrom	0.03
EnBW	0.01
Aral	0.01

Breakdown by network (Aral) back

Plan	Share of net
Aral	0.23
Other	0.22
ADAC e-Charge mit Aral pulse	0.12
MAINGAU Autostrom	0.11
Ionity	0.11
EnBW	0.08
ADAC e-Charge mit EnBW	0.08
Ad-hoc	0.06

Breakdown by network (Allego) back

Plan	Share of net
Other	0.44
ADAC e-Charge mit EnBW	0.18
MAINGAU Autostrom	0.13
Ad-hoc	0.10
Ionity	0.08
EnBW	0.07

Breakdown by network (EWE Go) back

Plan	Share of net
Own	0.49
Other	0.22
MAINGAU Autostrom	0.11
EnBW	0.07
Ad-hoc	0.04
Ionity	0.04
ADAC e-Charge mit EnBW	0.03

Breakdown by network (Shell) back

Plan	Share of net
Own	0.38
Other	0.24
MAINGAU Autostrom	0.14
ADAC e-Charge mit EnBW	0.11
EnBW	0.08
Ad-hoc	0.05

Breakdown by network (E.ON) back

Plan	Share of net
Other	0.57
ADAC e-Charge mit EnBW	0.14
Ad-hoc	0.11
MAINGAU Autostrom	0.06
EnBW	0.06
Own	0.03
Ionity	0.02

Breakdown by network (Fastned) back

Plan	Share of net
EnBW	0.29
Other	0.19
Ad-hoc	0.13
MAINGAU Autostrom	0.13
Own	0.10
Ionity	0.10
ADAC e-Charge mit EnBW	0.06

EnBW roaming usage, by tariff level back

Network	S	M	L
EnBW	0.42	0.53	0.73
Aral pulse	0.10	0.09	0.06
allego	0.07	0.08	0.02
E.ON	0.07	0.04	0.01
EWE Go	0.05	0.05	0.02
Mer	0.03	0.01	0.00
TotalEnergies	0.02	0.00	0.00
Fastned	0.02	0.03	0.02
IONITY	0.02	0.01	
Pfalzwerke	0.01	0.01	0.01

- S: free, M: €5.99/month, L: €17.99/month

ADAC (EnBW) roaming plan usage back

Network	Share
EnBW	0.44
Aral pulse	0.08
allego	0.08
E.ON	0.05
EWE Go	0.04
Fastned	0.04
Comfortcharge	0.02
be.energised	0.02
NewMotion	0.02
Mer	0.02

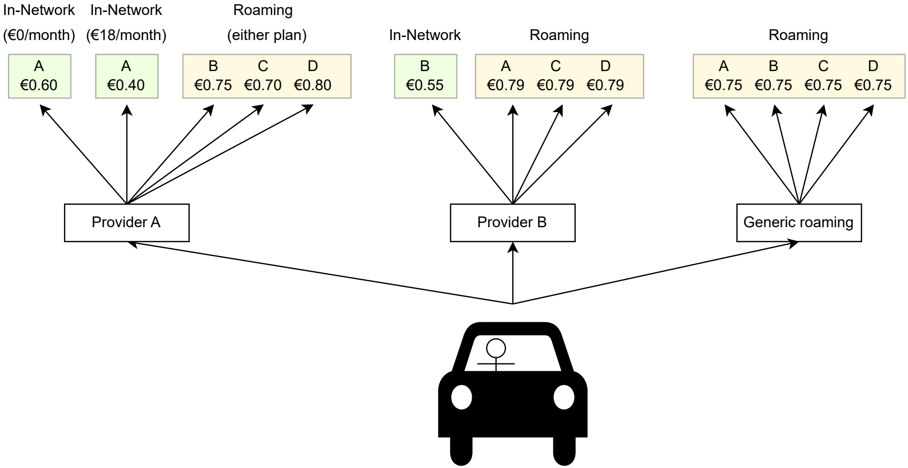
Ionity-affiliated plan usage back

Network	Share
IONITY	0.51
EnBW	0.13
Aral pulse	0.09
allego	0.06
EWE Go	0.04
Fastned	0.02
E.ON	0.02
be.energised	0.02
Pfalzwerke	0.01
Mer	0.01

Maingau roaming plan usage (top 10)

Network	Share
EnBW	0.20
Aral pulse	0.15
allego	0.12
E.ON	0.08
Fastned	0.07
EWE Go	0.05
Mer	0.03
Comfortcharge	0.03
be.energised	0.03
IONITY	0.03

Consumer decision



VI FOC (ad-hoc price) back

$$0 = \underbrace{\sum_{\theta\in\Theta} \frac{\partial}{\partial p_A} D_A^{Ad-hoc}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_A - c) + D_A^{Ad-hoc}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)}_{\text{Change in ad-hoc sales}}$$

$$+ \underbrace{\sum_{\theta\in\Theta} \frac{\partial}{\partial p_A} D_{AA}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_{AA} - c)}_{\text{Change in sales to plan consumers}}$$

$$+ \underbrace{\sum_{\theta\in\Theta} \sum_{j\in J} \frac{\partial}{\partial p_A} D_{Aj}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_{Aj} - p_j)}_{\text{Substitution between in-network and out of network}}$$

$$+ \underbrace{\sum_{\theta\in\Theta} \sum_{n\neq A} \frac{\partial}{\partial p_A} D_{nA}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)(p_A - c)}_{\text{Change in amount of roaming from external customers}}$$

VI FOC (plan price) back

$$0 = \underbrace{\sum_{\theta \in \Theta} \frac{\partial}{\partial p_{AA}} D_A^{Ad-hoc}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_A - c)}_{\text{Change in ad-hoc sales}}$$

$$+ \underbrace{\sum_{\theta \in \Theta} \frac{\partial}{\partial p_{AA}} D_{AA}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_{AA} - c) + D_{AA}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)}_{\text{Change in sales to plan consumers}}$$

$$+ \underbrace{\sum_{\theta \in \Theta} \sum_{j \in J} \frac{\partial}{\partial p_{AA}} D_{Aj}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_{Aj} - p_j)}_{\text{Substitution between in-network and out of network}}$$

$$+ \underbrace{\sum_{\theta \in \Theta} \sum_{n \neq A} \frac{\partial}{\partial p_{AA}} D_{nA}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)(p_A - c)}_{\text{Change in amount of roaming from external customers}}$$

VI FOC (roaming price) back

$$0 = \underbrace{\sum_{\theta \in \Theta} \frac{\partial}{\partial p_{Aj}} D_A^{Ad-hoc}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_A - c)}_{\text{Change in ad-hoc sales}}$$

$$+ \underbrace{\sum_{\theta \in \Theta} \frac{\partial}{\partial p_{Aj}} D_{AA}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_{AA} - c)}_{\text{Change in direct sales}}$$

$$+ \underbrace{\sum_{\theta \in \Theta} \sum_{j \in J} \frac{\partial}{\partial p_{Aj}} D_{Aj}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_{Aj} - p_j) + D_{Aj}(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)}_{\text{Substitution between in-network vs out of network}}$$

$$+ \underbrace{\sum_{\theta \in \Theta} \sum_{n \neq A} \frac{\partial}{\partial p_{Aj}} D_{nA}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)(p_A - c)}_{\text{Change in amount of roaming from external customers}}$$

Non-VI FOC back

$$
\begin{aligned}
0 &= \frac{\partial \Pi_j(\boldsymbol{p}, \boldsymbol{\tau}, \Omega_A, \Omega_r)}{\partial p_j} \\
\iff 0 &= \underbrace{\sum_{\theta \in \Theta} \frac{\partial}{\partial p_j} D_j(\boldsymbol{p}, \Omega_A, \Omega_{-A}, \theta)(p_j - c) + D_j(\boldsymbol{p}, \Omega_A, \Omega_r, \theta)}_{\text{Change in ad-hoc sales}} \\
&+ \underbrace{\sum_{\theta \in \Theta} \sum_{n \in N} \frac{\partial}{\partial p_j} D_{nj}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)(p_j - c) + D_{nj}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)}_{\text{Change in roaming from external consumers}}
\end{aligned}
$$

Roaming FOC

$$
\begin{aligned}
& 0 = \frac{\partial \Pi_n(\boldsymbol{p}, \boldsymbol{\tau}, \Omega_n, \Omega_{-n})}{\partial p_n} \\
\iff & 0 = \underbrace{\sum_{\theta \in \Theta} \sum_{j \in J} \frac{\partial}{\partial p_n} D_{nj}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)(p_n - p_j) + D_{nj}(\boldsymbol{p}, \Omega_n, \Omega_{-n}, \theta)}_{\text{Change in roaming profits}}
\end{aligned}
$$

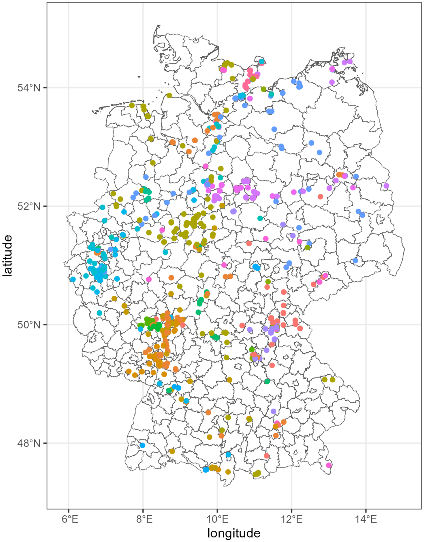
&-Charge.com data

- I now present some descriptive analysis of the checkin data from &-Charge
- Nearly 600,000 charging events from around 16,000 unique users
- Charge events per user: (> 1 charge, truncated at 95th percentile)

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
2.00	10.00	29.00	68.79	87.00	496.00

- The main takeaways:
  - Drivers do most of their charging at one network
  - There is a decent amount of persistence in consumers' charging choices over time
  - Large, VI networks seem to better retain users, small networks are used more as a supplement

Map of 20 randomly selected users' charges



Individual shares (if charged at network)

net	med_share	mean_share
EnBW	0.42	0.49
Ionity	0.2	0.31
Aral pulse	0.15	0.25
Allego	0.33	0.51
E.ON Drive Infrastructure	0.08	0.16
EWE Go	0.12	0.22
Shell Recharge	0.09	0.18
Fastned	0.07	0.17
TotalEnergies	0.05	0.14
PFALZWERKE	0.17	0.32

- Example: across all users who have ever charged at EnBW, the median (mean) share of charging done at EnBW is 42% (49%)
- Distinction: primary vs supplementary networks

Usage share (of top network)

net	mean_share	med_share	N
EnBW	0.68	0.67	3800
Allego	0.86	1.00	2299
Ionity	0.62	0.50	1005
Aral pulse	0.64	0.57	635
PFALZWERKE	0.76	1.00	597
EWE Go	0.66	0.62	380
Shell Recharge	0.59	0.50	220
E.ON Drive Infrastructure	0.67	0.50	163
Fastned	0.65	0.50	108
TotalEnergies	0.67	0.50	71

Usage share of top network (users with more than 5 charges)

net	mean_share	med_share	N
EnBW	0.50	0.45	1650
Ionity	0.48	0.43	479
Allego	0.37	0.33	270
Aral pulse	0.42	0.38	254
PFALZWERKE	0.50	0.44	193
EWE Go	0.41	0.38	118
Shell Recharge	0.37	0.33	105
E.ON Drive Infrastructure	0.36	0.27	32
Fastned	0.43	0.44	21
TotalEnergies	0.33	0.31	18

Monthly share of top net

- Averaging across all time not necessarily ideal as it obscures variation over time
- For instance, a consumer may switch from a generic roaming plan to a paid EnBW plan
- Their top network would change over time, which would show a overall lower share of total charging done at their primary network (even if they do most of their charging with their primary network at that point in time)

Charging done at consumer's top network, monthly

net	mean_sh	med_sh	N
EnBW	0.79	1.00	11482
Allego	0.80	1.00	4142
Ionity	0.73	0.75	3637
Aral pulse	0.76	1.00	2505
PFALZWERKE	0.80	1.00	2215
EWE Go	0.76	1.00	1455
Lidl	0.73	1.00	1301
Shell Recharge	0.69	0.67	1218
Tesla Supercharger	0.81	1.00	1207
Kaufland	0.79	1.00	993

- Takeaway: within a given month, consumers do a majority of their charging within one network

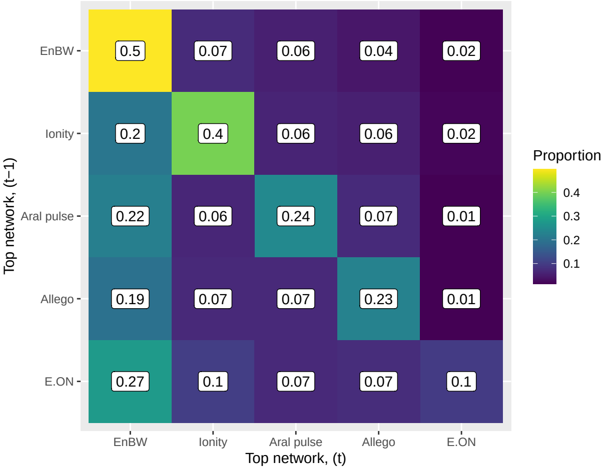
Monthly share at top network (>1 charge event)

net	mean_sh	med_sh	N
EnBW	0.70	0.67	5636
Ionity	0.66	0.67	1794
Allego	0.61	0.50	1179
PFALZWERKE	0.67	0.67	944
Aral pulse	0.62	0.60	936
Shell Recharge	0.54	0.50	691
Lidl	0.61	0.57	596
EWE Go	0.62	0.60	484
Tesla Supercharger	0.66	0.67	482
Kaufland	0.63	0.60	387

Transition of top network

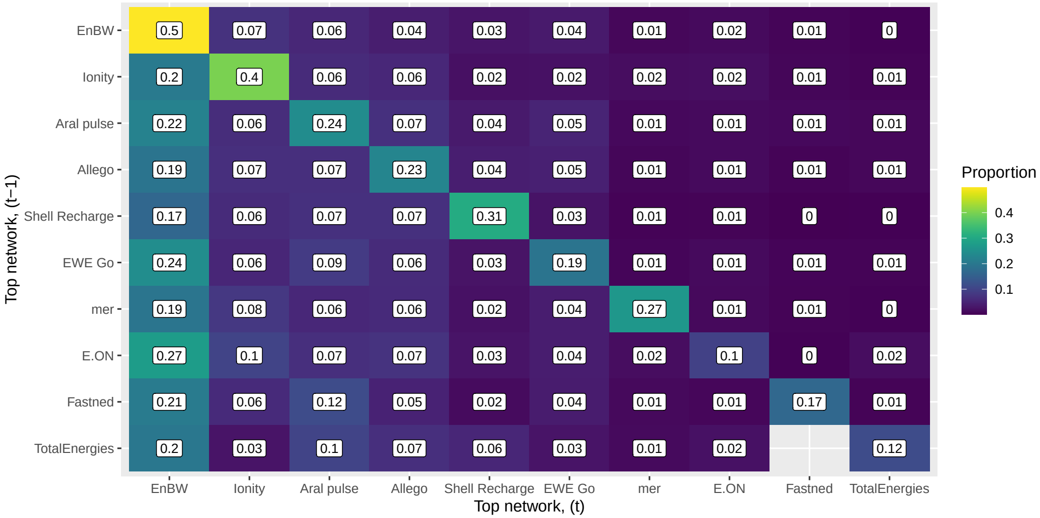
- I also document how consumers' top network evolves over time
- The model predicts:
  - There will be some degree of persistence in a consumer's most-used network from month to month (revealed preference)
  - This persistence will be stronger for consumers who have a plan with a VI network and get a volume discount
  - Consumers with such a plan will be more likely to go back to the plan's network (even after charging out of network)
- To illustrate this, I compute the transition matrix for consumers' top network from month to month
- For each network A and B:
  - I compute the proportion of users whose top network is A at time $t-1$ and B at time t
  -

Top network transition



- Note: the cell in row i, column j is the proportion of consumers whose top network was i in month $t-1$ and j in month t

Top network transition (more nets)



Top network transition

- Caveat: this is averaging over all users, each with different plans/roaming prices/volume discounts
- Nevertheless, there are some interesting patterns:
  1. Asymmetry of transition: e.g. Aral to EnBW much more likely than EnBW to Aral
  2. EnBW has highest persistence, followed by Ionity (both VI providers offering volume discounts as well as roaming)
  3. EnBW has a lot more ‘returning’ customers (first column): consistent with membership idea
  4. Certain networks have far lower ‘retention’ than others - suggests that these are not consumers’ primary network
- Helps reveal potential substitution patterns and correlation of consumer preferences