Social Equity of Clean Energy Policies in Electric-Vehicle Charging Infrastructure Systems

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Background: Energy Divide

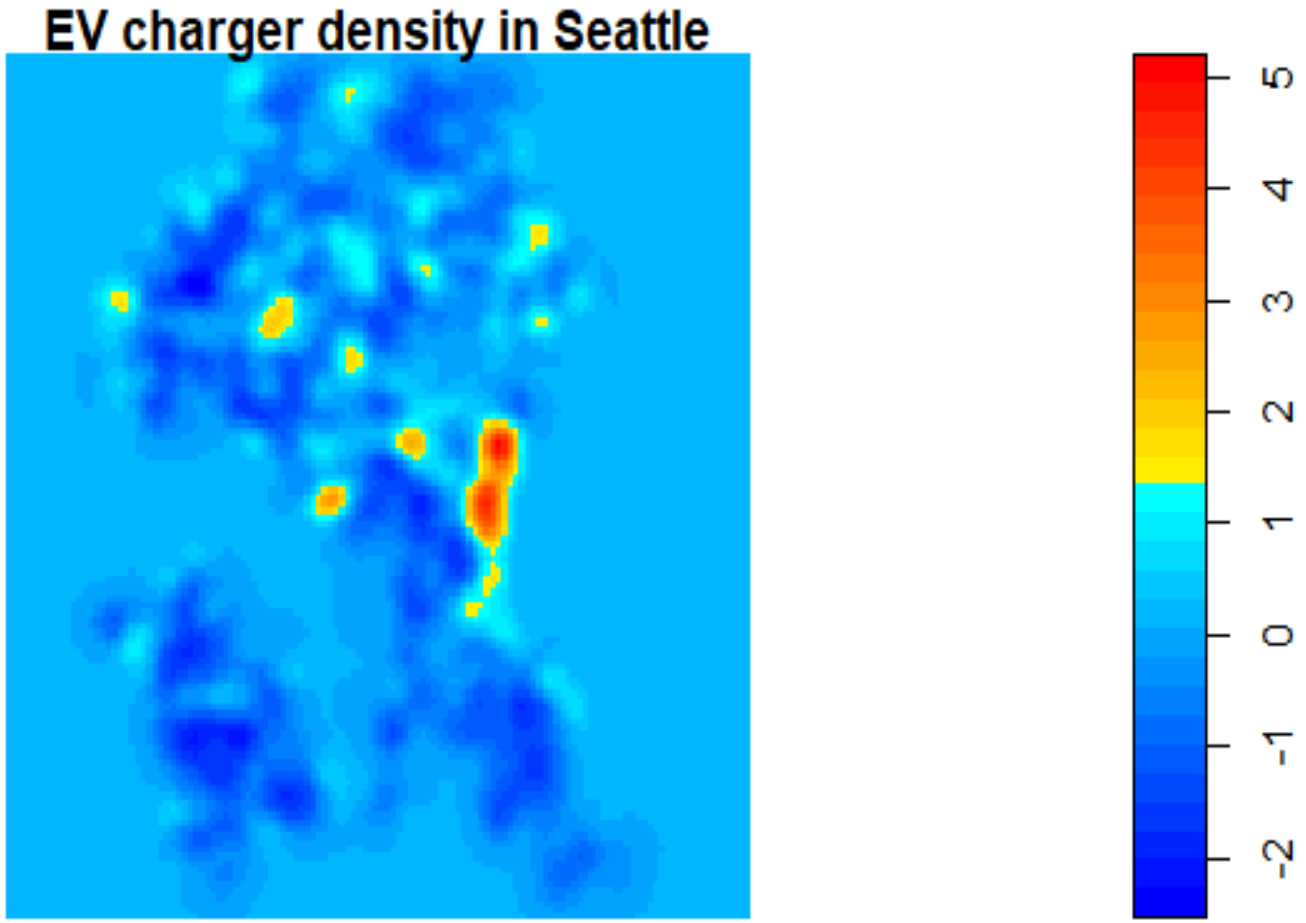
- The rapid transition to the new energy system due to the clean energy policies - digital divide of the late 20th century.
- Uneven distribution of the service such as EV charging infrastructure.

Residential EV Charger in Seattle

Rapidly increased with advancement of clean energy policies.

- Are there certain communities left out from incentive opportunities?
- Do those current policies affect the social equity?

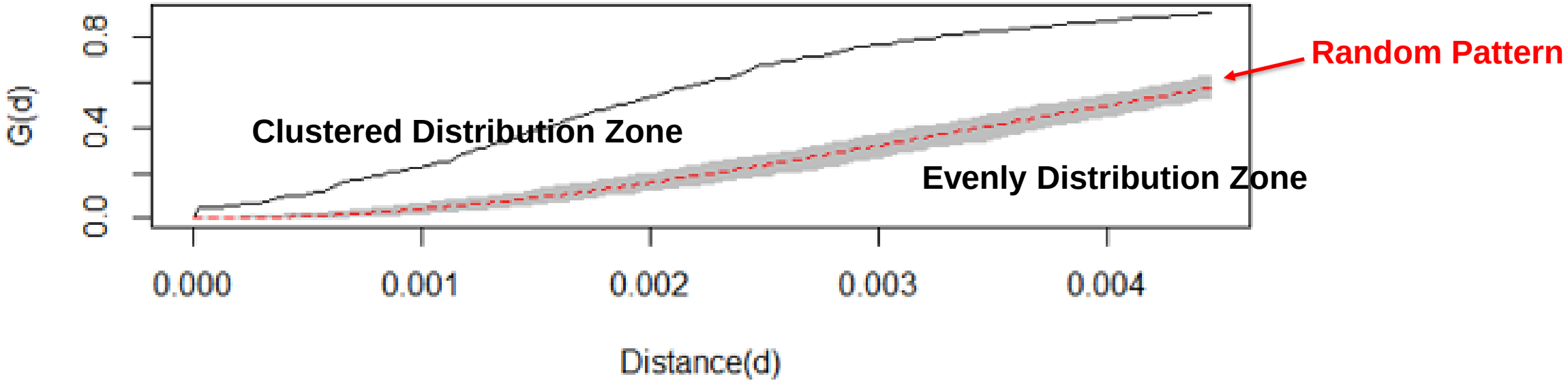
Clustering on Distribution



EV charger density normalized by the number of residential house units.

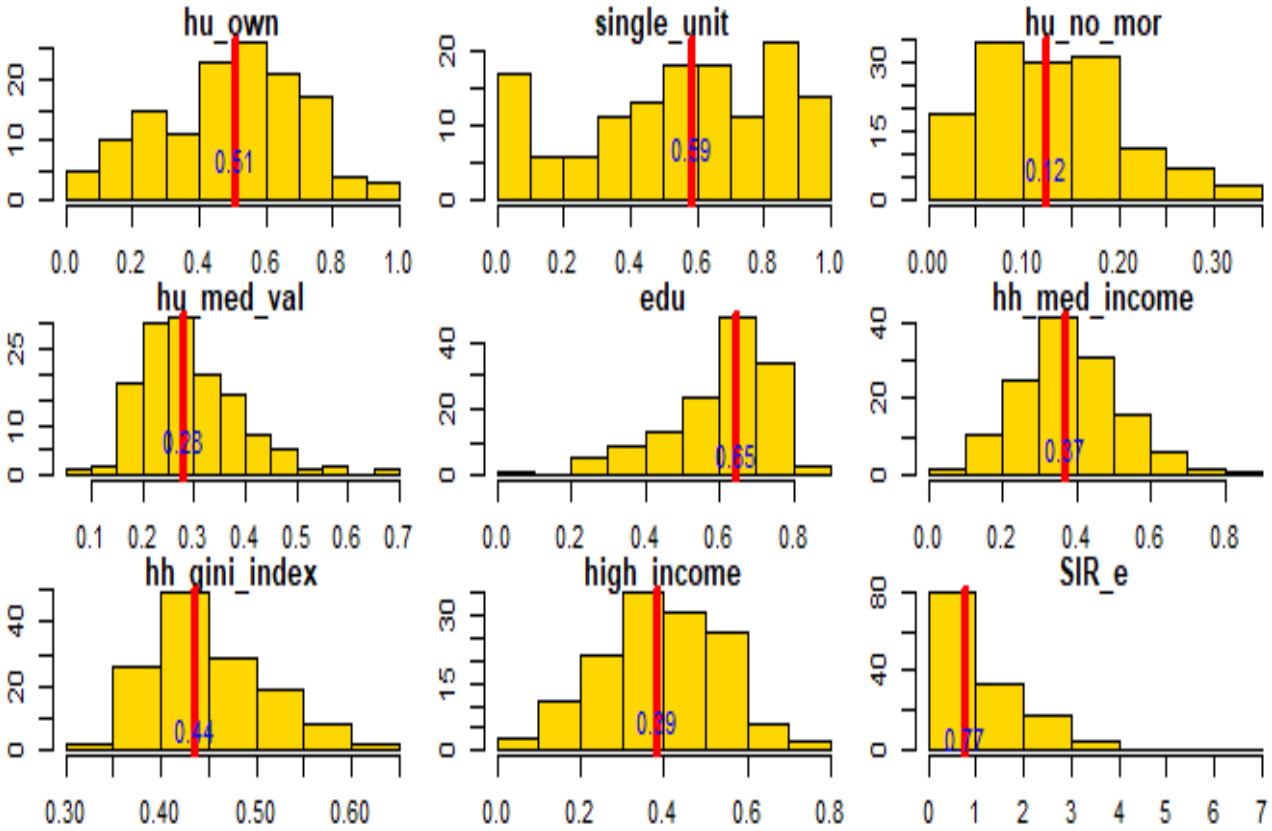
G Estimate for Spatial Dependency

$$\hat{G}(d) = \frac{\#\{d_i \leq d\}}{n}.$$



G estimate showing the spatial dependency

Socio-economic Characteristics

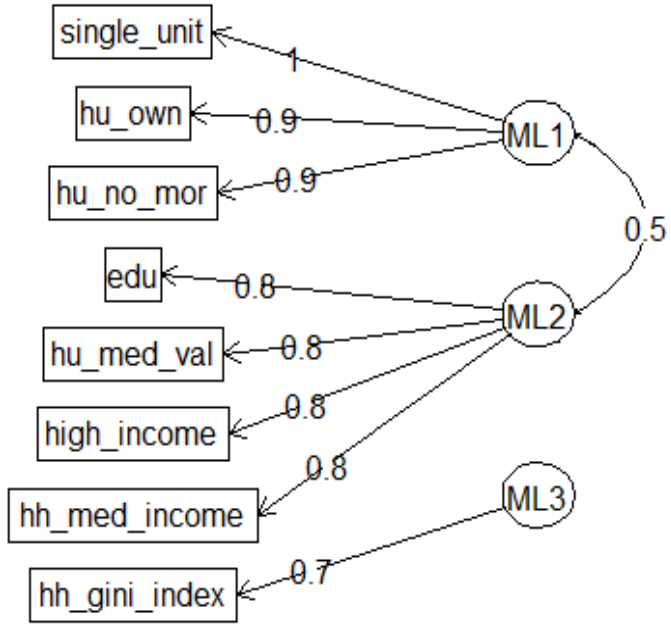


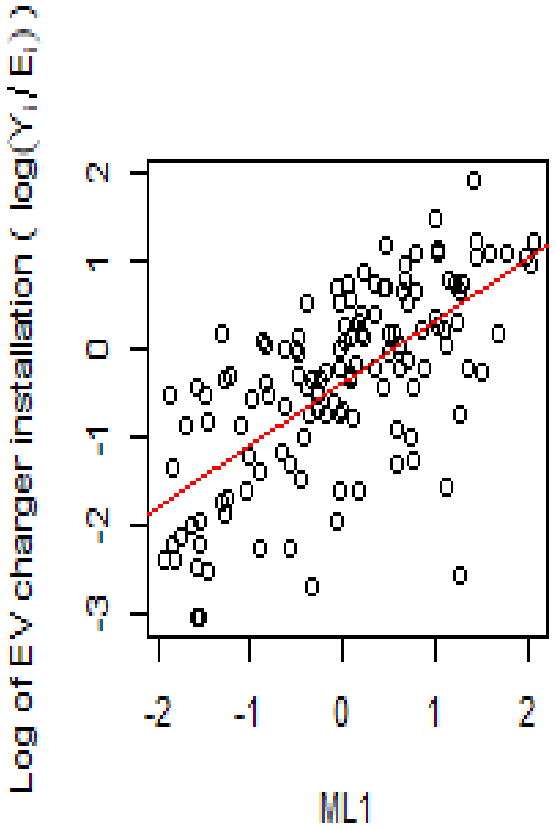
- **8 Variables**
  - Owner-occupied
  - Single family
  - Owner-occupied w/o mortgages
  - Median value of owner-occupied
  - Population above high school degree
  - Household median income
  - Household GINI Index of income inequality
  - High income households

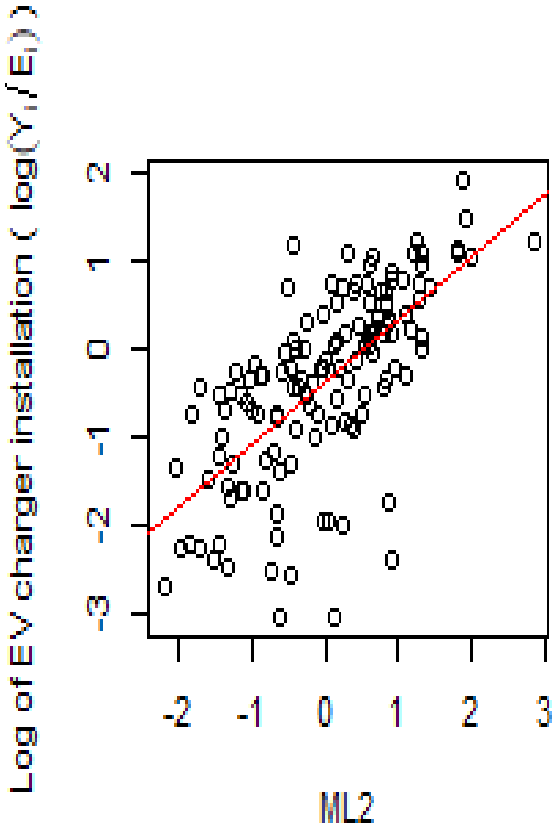
- **SIR_e**: Installation Ratio

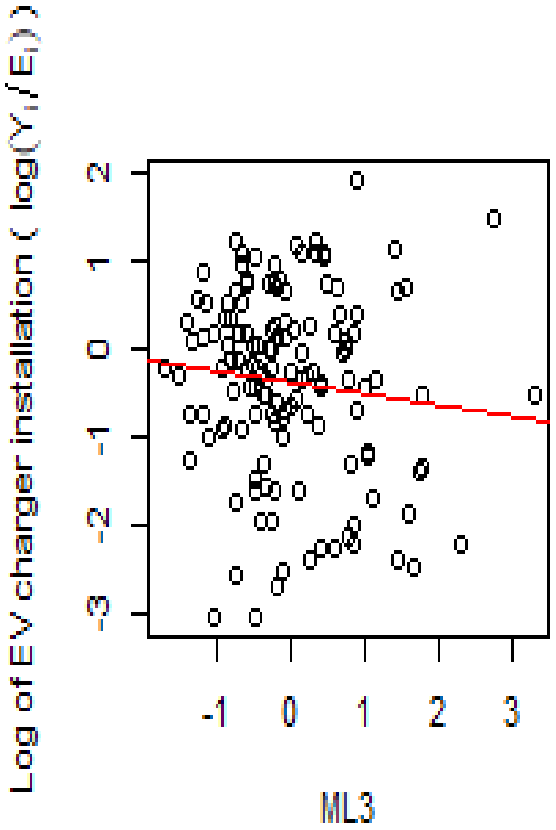
$$\frac{\text{Number of Residential EV Charger}}{\text{Expected Number regarding Housing Units}}$$

Latent Variables









- **ML1 : Housing structure and tenure**
- **ML2 : Economic status**
- **ML3 : Inequality**

Intrinsic Conditional Auto-Regressive

- **Large variance from spatial dependency**
- **Φ (Phi) is 0.85**

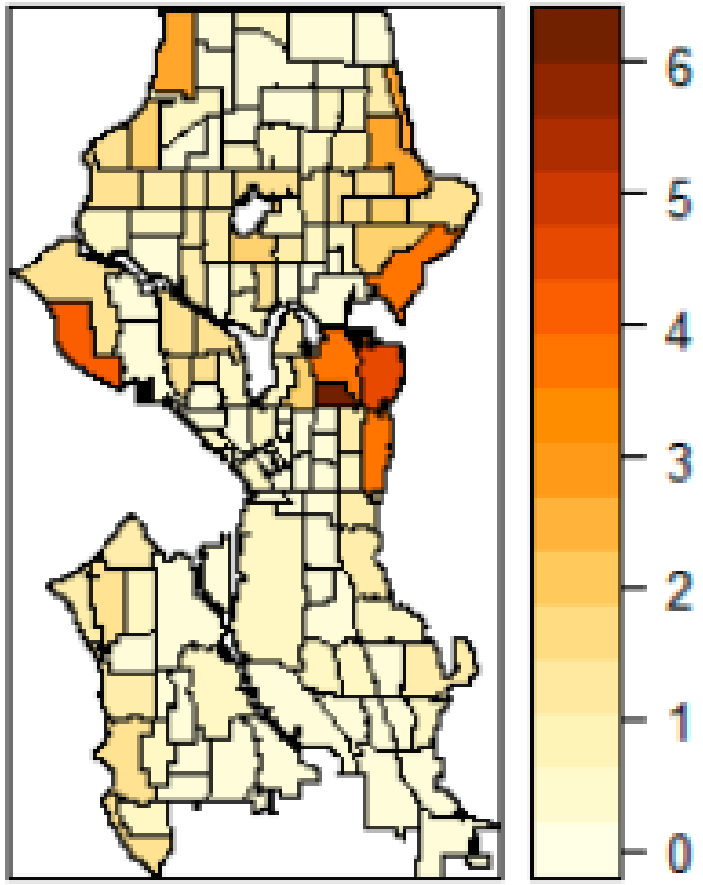
	mean	0.025quant	0.5quant	0.975quant
(Intercept)	-0.2474	-0.3409	-0.2468	-0.1576
I(ML1)	0.3383	0.1917	0.3391	0.48
I(ML2)	0.5301	0.3847	0.5288	0.6831
I(ML3)	0.1387	0.02818	0.1388	0.249
Total residual sd	0.3532	0.5082	0.3662	0.2554
Phi for ID	0.7896	0.316	0.8459	0.9893

Spatial Autocorrelation Model (BYM2) by INLA

$$
\begin{aligned}
Y_i|\beta_0,\beta_1,\beta_2,\beta_3,S_i,\epsilon_i &\underset{ind}{\sim} \text{Poisson}(E_i e^{\beta_0+\beta_1 I_{1i}+\beta_2 I_{2i}+\beta_3 I_{3i} e^{S_i+\epsilon_i}}),\\
\epsilon_i|\sigma_\epsilon^2 &\underset{iid}{\sim} \text{N}(0,\sigma_\epsilon^2),\\
S_1,\ldots,S_n|\sigma_s^2 &\sim \text{ICAR}(\sigma_s^2).
\end{aligned}
$$

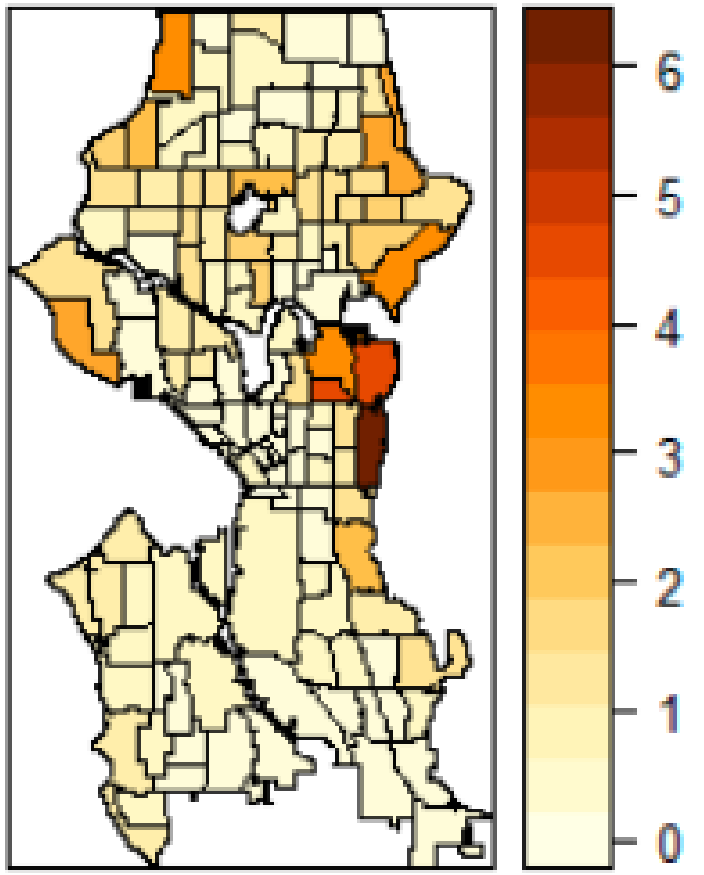
ICAR Model Mapping

Covariate RRs (BYM2)



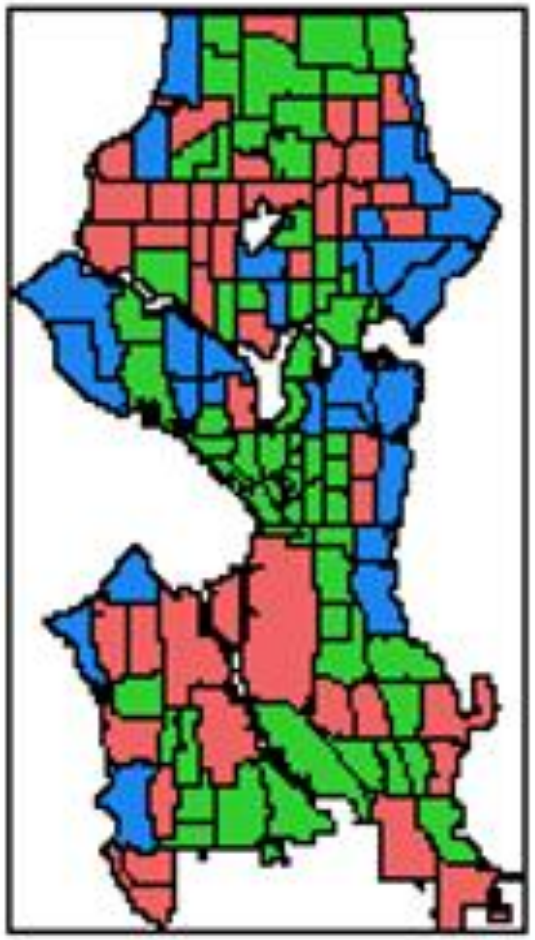
Housing Stability & Economic Status

Lognormal-Spatial RRs (BYM2)

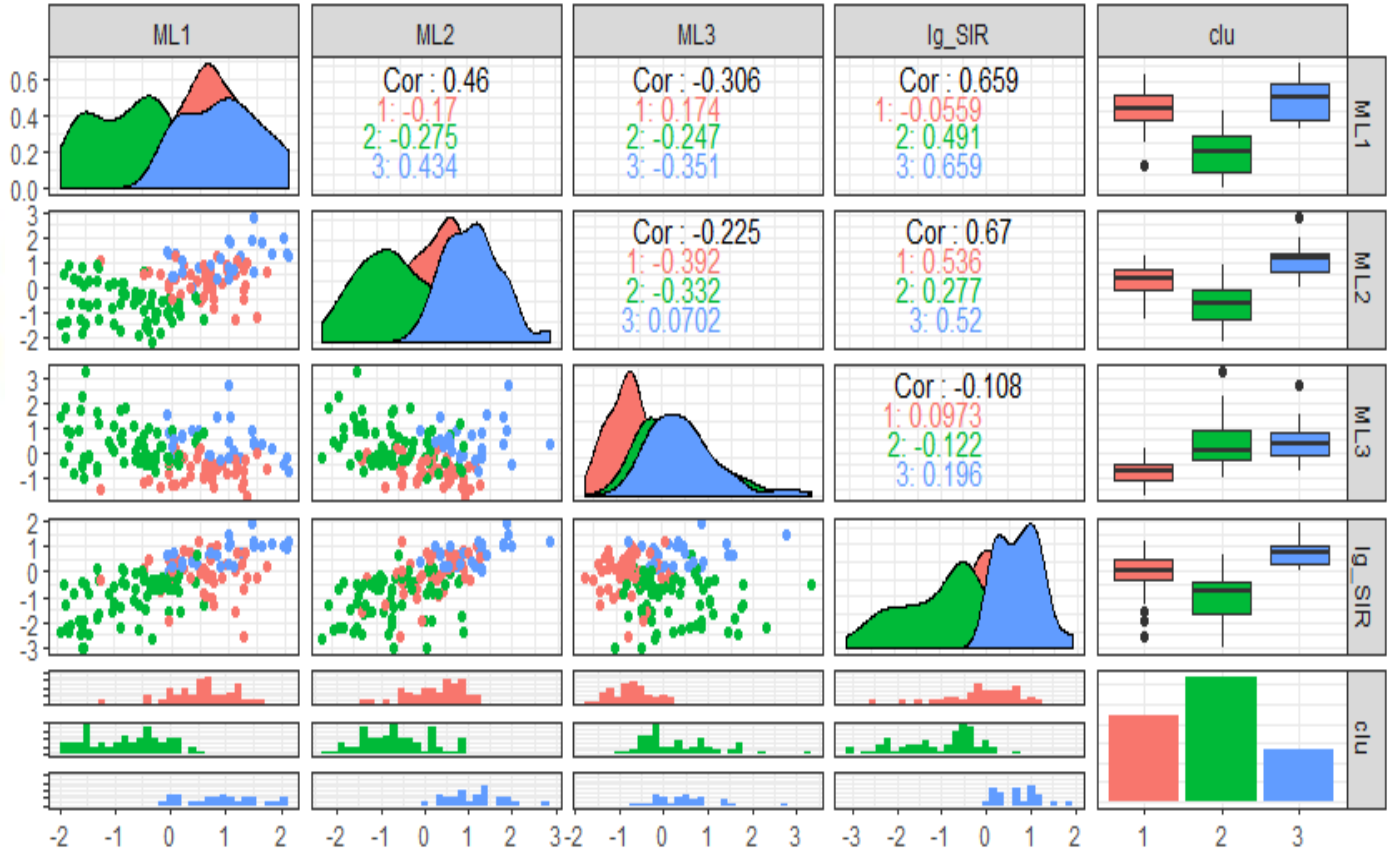


EV Charger Installation

K-Means Clustering



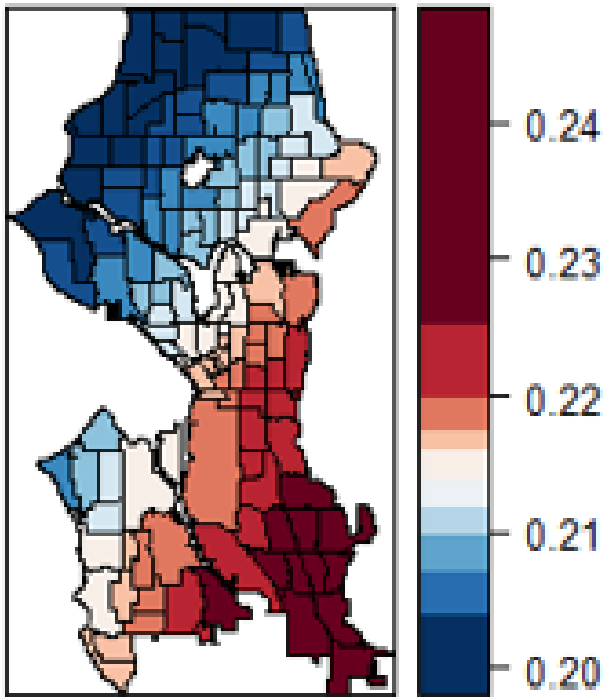
Blue cluster following the higher EV charger installation pattern



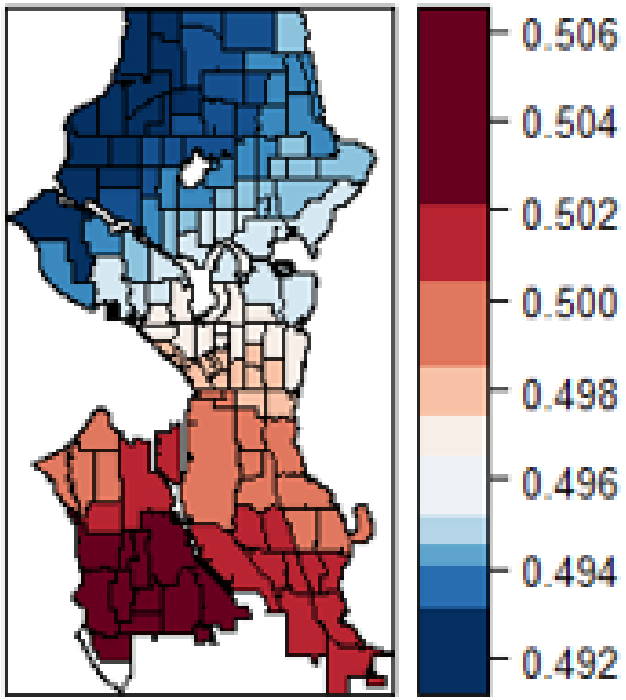
Geographically Weighted Regression

- Spatial dependence at a local level

$$Y(s) = E(s)\mathrm{e}^{(\beta_0+\beta_1(s)X_1(s)+\beta_2(s)X_2(s)+\epsilon(s))}$$



ML1: Housing Stability Sensitivity

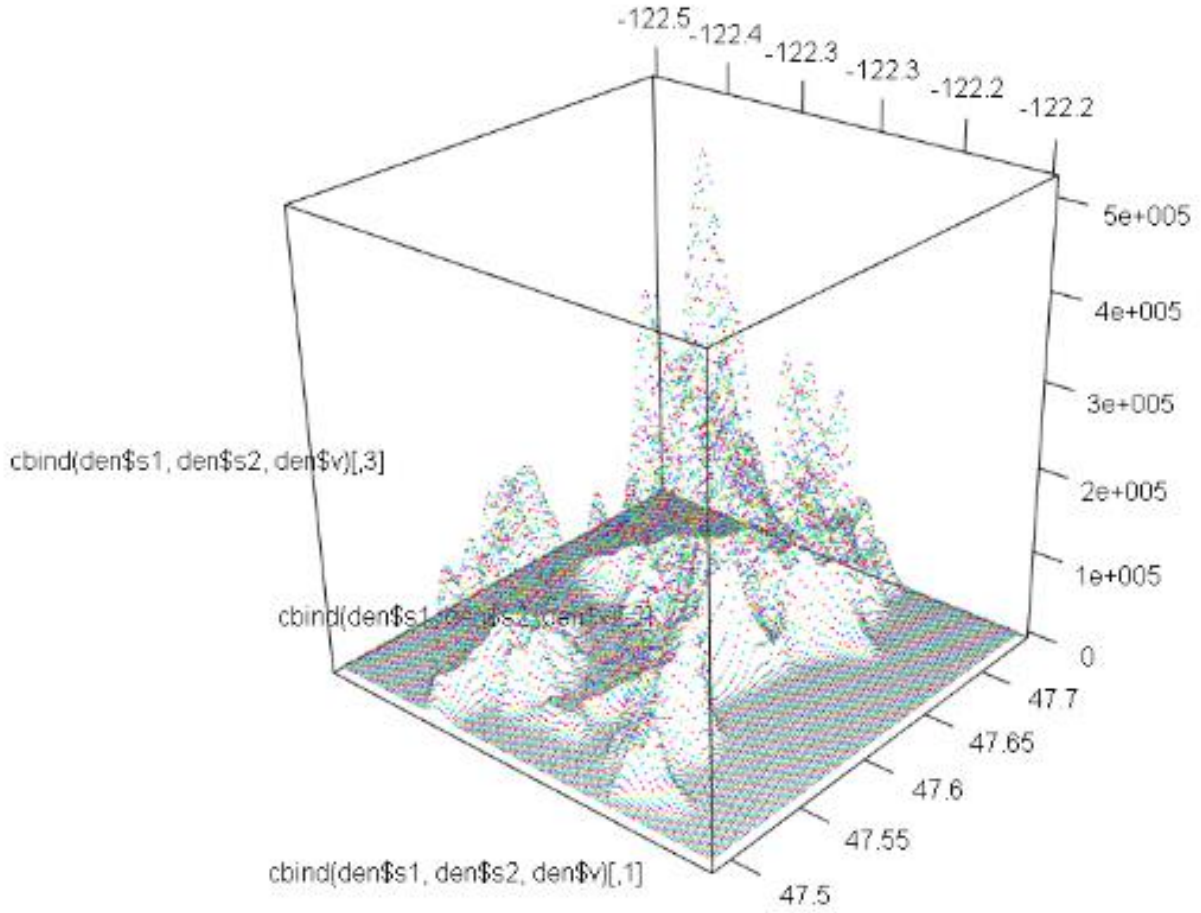


ML2: Economic Status Sensitivity

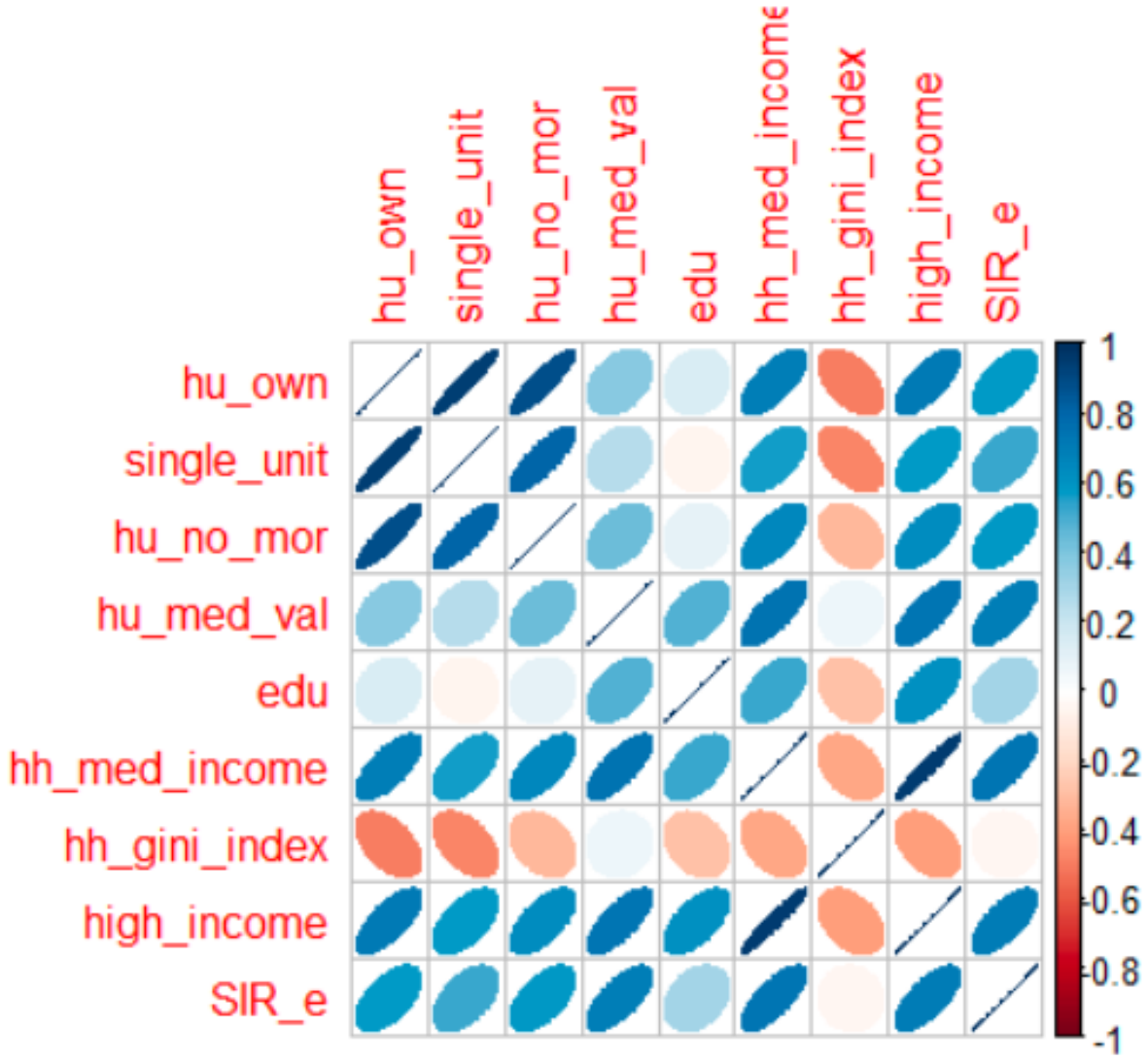
Conclusions

- **Social equity:**
  - Uneven distribution of EV charger
- **Significant factors:**
  - Economic Status
  - Housing Stability
- **Spatial autocorrelation**
- **Sensitive regions** identified to increase EV for even distribution
  - Southwest – Economic status
  - Southeast – Housing stability

Appendix – EV Charger 3D Density

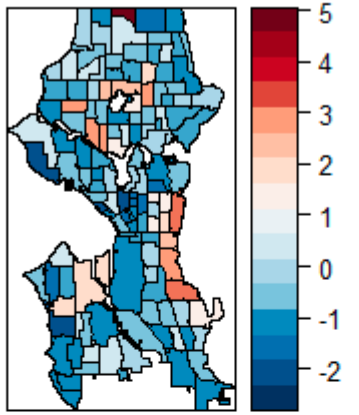


Appendix – Pairwise Covariates Correlation

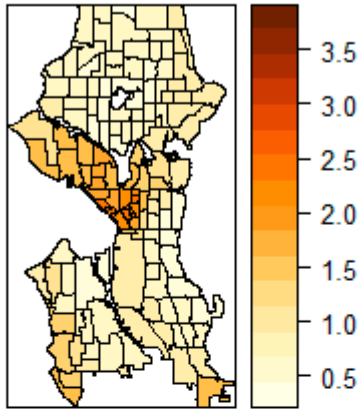


Appendix – Random Effects

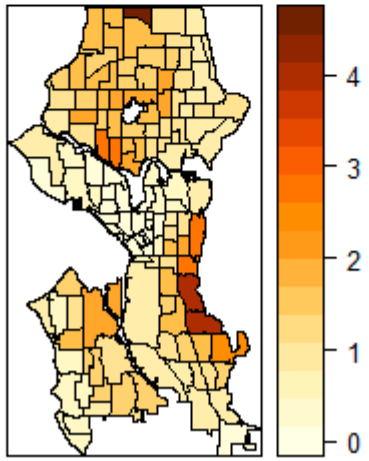
Residuals of poission with covariates model



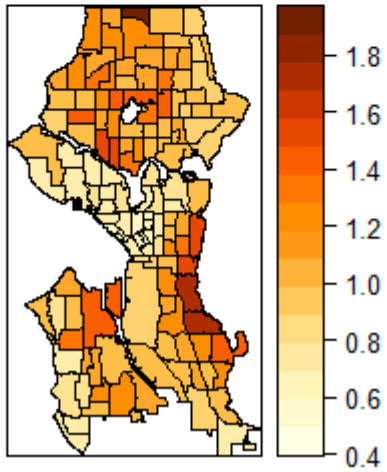
Non-spatial random effects (BYM2)



Spatial random effects (BYM2)



Total random effects (BYM2)



Appendix - Prediction (Gradient Boosted Random Forest)

- Max depth=2
- Learning rate=0.1
- Estimators=50
- Train to test=0.8
- 26 tree estimators
- Most important feature of ML2