# Electric Vehicle Adoption:
## Spatial and Demographic Effects

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# Motivation

- Where will PEV owners live? What factors influence adoption?
  - Public charging infrastructure
  - Distribution and transmission upgrades
  - Targeted marketing, sales, and distribution
  - Incentive design
- Two important questions:
  - Are there spatial patterns in direct econometric modeling of consumer hybrid electric vehicle adoption?
  - If there are patterns, what factors influence consumer adoption?
- Use econometric models to estimate influence

# Modeling Approach:
## Single-Parameter

- Spatial heterogeneity modeled as explanatory or unobserved (residual) variable or both
- Spatial Autoregressive: $y = \rho W y + X\beta + \epsilon, \epsilon \sim N(0, \sigma^2 I_n)$
- Spatial Errors: $y = X\beta + u, u = \lambda W u + \epsilon, \epsilon \sim N(0, \sigma^2 I_n)$
- General Spatial: $y = \rho W_1 y + X\beta + u, u = \lambda W_2 u + \epsilon, \epsilon \sim N(0, \sigma^2 I_n)$
  - $y$ is a vector of observations of PEV adoption
  - $X$ is a matrix of explanatory variables
  - $\rho$ and $\lambda$ are spatial coefficients
  - $W$, $W_1$, and $W_2$ are spatial weight matrices

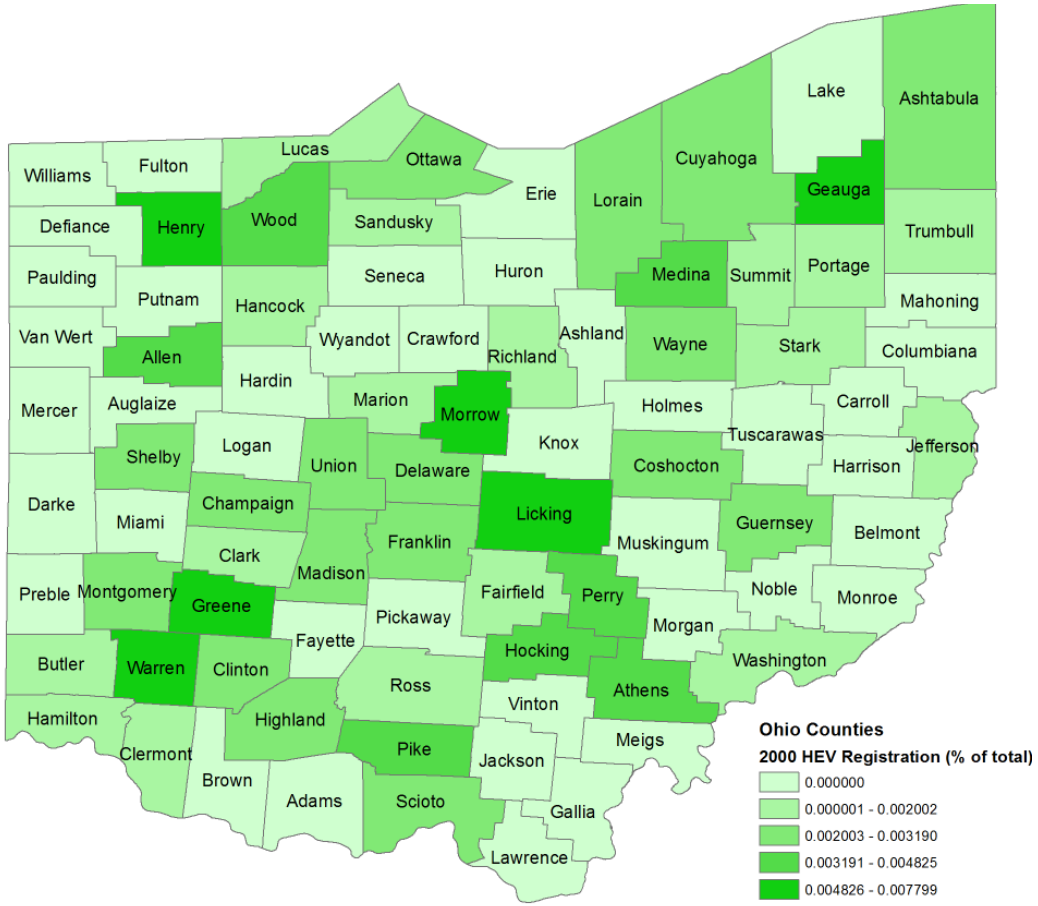
# Modeling Approach:
## Spatial Heterogeneity

- Spatial heterogeneity modeled as locational estimates for all variables
- Geographically Weighted: $W_i^{1/2} y = W_i^{1/2} X \beta_i + W_i^{1/2} \epsilon_i$
  - Exponential Decay: $W_i = \sqrt{\exp(-d_i/\theta)}$
  - Gaussian Decay: $W_i = \varphi(d_i/\sigma\theta)$
  - $y$ and $X$ are as before
  - $W_i$ is the spatial weight matrix for location $i$
  - $d_i$ denotes the Euclidean distance between location $i$ and other locations
  - $\sigma$, $\theta$, and $\varphi$ denote standard deviation of $d_i$, bandwidth, and Gaussian density, respectively

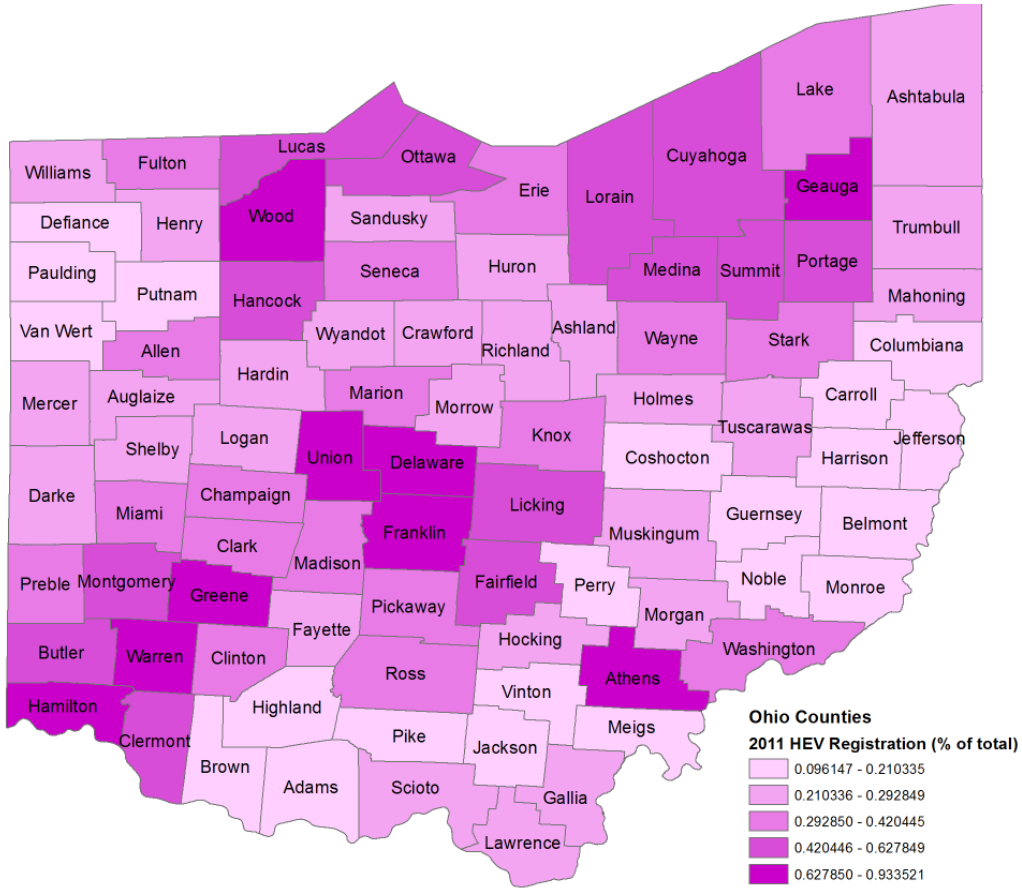
# Data
(Preliminary)

- County-level vehicle registration data for Ohio in 2000 and 2011, obtained from R.L. Polk and Co.
- County-level demographic data from the U.S. Census Bureau
  - Independent variable: county-level HEV adoption percentage
  - Dependent Variables:
    - Smog check county
    - Median age (average: 39.1 years)
    - Percent of population with annual income greater than or equal to $60,000 (average: 36.6%)
    - Percent of population with a bachelor's degree or higher (average: 23.0%)
    - Population per square mile (average: 290 people per square mile)

# Data
## Spatial Adoption Maps




2000 Adoption




2011 Adoption

# Results (2000)

## Summary Statistics

- Mean: 1.94 cars
- Standard Deviation: 3.78 cars
- Min: 0
- Max: 22
- Total: 171 cars
- Number of counties within sample: 88
- Excludes out-of-state registrations

# Results (2000)
## Model Estimates

| Variable | Estimate | Standard Error | *p*-value |
|---|---|---|---|
| Constant | 1.01 | 0.29 | 0.36 |
| Smog | -0.46 | 0.08 | 0.28 |
| Median Age | -0.10** | 0.01 | 0.05 |
| Income | 0.02 | 0.00 | 0.22 |
| Education | 0.08 | 0.01 | 0.14 |
| Pop. Density | 1.5E-3*** | 0.00 | 0.01 |
| $\rho$ | 0.15*** | 0.01 | 0.00 |

NB: ***, **, and * denote significance at 0.01, 0.05, and 0.10 levels, respectively

# Results (2011)

## Summary Statistics

- Mean: 553.47 cars
- Standard Deviation: 1,143.57 cars
- Min: 13
- Max: 6,762
- Total: 48,705 cars
- Number of counties within sample: 88
- Excludes out-of-state registrations

# Results (2011)
## Model Estimates

| Variable | Autoreg | Spatial Error | General Spatial | Exponential | Gaussian |
|---|---|---|---|---|---|
| Constant | 0.09 | 0.12 | 0.23 | 0.11 | 0.12 |
| Smog | -0.03 | -0.03 | -0.02 | -0.04 | -0.04 |
| Median Age | -0.02*** | -0.02*** | -0.02*** | -0.02*** | -0.02*** |
| Income | 0.01*** | 0.01*** | 0.01*** | 0.01*** | 0.01*** |
| Education | 0.02*** | 0.02*** | 0.02*** | 0.02** | 0.02** |
| Pop. Density | 7.3E-5*** | 8.4E-5*** | 8.6E-5*** | 5E-5*** | 5E-5*** |
| $\rho$ | 0.11 | | -0.09*** | | |
| $\theta$ | | | | 4.08 | 2.80 |
| $\lambda$ | | 0.22 | 1.68*** | | |
| $R^2$ | 0.81 | 0.82 | 0.90 | 0.82 | 0.81 |
| Log-likelihood | 128.67 | 128.99 | 132.32 | | |

NB: ***, **, and * denote significance at 0.01, 0.05, and 0.10 levels, respectively

# Conclusions

- More-educated people, people with higher income, and counties with high population density are more likely to adopt PEVs
- Older people are less likely to adopt PEVs
- Spatial correlation is present in the 2000 and 2011 data
  - Spatial models are needed, otherwise parameter estimates are inconsistent
- Although current adoption in one county negatively influences adoption in neighboring counties in the 2011 data, spatial heterogeneity that positively influences adoption is not fully modeled

# Future Work

- Work with finer-grained adoption data
  - In talks with Ohio Bureau of Motor Vehicles
  - Our understanding of the law is that we can obtain VINs at the street address level
  - Currently have a preliminary dataset at the tax-district level, while awaiting these
- Cross-reference with census block demographic and socioeconomic data
- Should provide more robust spatial correlation estimates

# Applications

- Inform ongoing work examining PEV integration, including:
  - Optimal location of public chargers
  - Transformer aging and charging control algorithm testing
  - Network upgrade planning