Measuring and examining the spatiotemporally varying transmissibility of COVID-19

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Outline

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Background

--Measuring transmissibility

$R_0$: Basic Reproduction Number

$R_e$: Effective Reproduction Number

--Complex relationships between contextual factors and the transmissibility

- There are multiple contributing factors affecting the transmissibility
- The relationships vary over time and space.
- Machine learning methods provide insights into the complex relationships
Research Questions

• **Question-1**
  - From a longitudinal perspective, for a specific place (e.g., county), how do policy and behavior responses to the pandemic affect the changing $R^e$ over time?

• **Question-2**
  - For a cross-sectional view, at a specific time, how is the spatial variability of $R^e$ associated with the demographic, socioeconomic, environmental, and health behavioral characteristics of places?
Methods

1. Estimation of transmissibility $R^e$

- Major steps for the estimation of space- and time-specific effective reproduction numbers ($R^e_{t,m}$)

$R^e_{t,m}$: the estimation of the effective reproduction number

$I_{t,m}$: the time series of active cases at time $t$ in county $m$

$\lambda_{t,m}$: the exponential growth rate of the time series of $I_{t,m}$
Methods

The flow of influences

Public Risk Perception
- The concern expressed by the public about the COVID-19 stimulates the behavioral changes

Government Interventions
- By issuing regulations, guidance, and recommendations, governments can intervene to change people’s behaviors

Climatic Factors
- PM2.5, temperature, and precipitation

Mobility Behaviors
- Activity frequencies and lengths of stay in various types of locations
  - ...

Safety Behaviors
- Frequent hand washing
- Wearing facial coverings
- Physical distancing
- Avoiding public places
- Taking vaccines
  - ...

2. Relationship between contributing context factors and $R^e$

Depletion of Susceptibles

Effective Contact Rate
- Frequency that an infectious individual contact with susceptibles

Infectious Period
- (can be considered biologically constant)

Infectiousness
- The likelihood of infection per contact with a susceptible person

Covid-19 Variants

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Methods

3. Machine learning models

- Two regression models
  - Linear Regression
  - Exponential Regression

\[ R_{m,t}^e = R_{m,0}^e e^{\sum_{i=1}^{n} \alpha_{m,i} \cdot x_{m,i}} \]

- Two Decision Tree Ensemble methods
  - XGBoost algorithm
  - Random Forest (RF)

- Artificial Neural Network (ANN)
Research Design

Background

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Conclusion

Daily cases statistics at the finest possible spatial scale (e.g., county level in the U.S. Mar. 2020 – Sep. 2021)

**\( R^e \) estimation algorithm**

A space-time dataset of daily \( R_{m,t}^e \) in place \( m \) and time \( t \)

**Place-specific time-series analysis** (Longitudinal)

- Place-specific Machine Learning models
- Predicted cases (Oct. 1 – Oct.31,2021)

**Local Context Characteristics**

- Policy and behavior changes in response to the pandemic, e.g., changes in:
  - human mobility
  - intervention policy
  - individual risk perception
  - Vaccination rate

- Demographic and socioeconomic characteristics, e.g.,
  - Racial composition
  - Age composition
  - Income level

**Time-specific spatial Analysis** (Cross-sectional)

- reported cases (Oct. 1 – Oct.31,2021)
- Time-specific GWR models

**Accuracy evaluation**

**RQ1**

**RQ2**
Results

1. **Estimation of \( R_e \) at the county level in the U.S. Mar. 2020 – Sep. 2021

*Fig. The variations of Covid-19 \( R_e \) in the United States across space and time*
Results

2. Machine models – Training and validation with training data

➢ To validate the models and assess their performances, the study applies the 10-fold cross-validation for each model.
Results

2. Machine models – Evaluation with testing data

- The figure shows prediction results of the RF and the exponential regression model, compared against reported cases for the six selected counties in October 2021.
Results

Exponential regression

- Each local model has a set of coefficients corresponding to the respective explanatory variables.
- The variable coefficients vary across space.

Spatial patterns of variable coefficients of the local exponential models

(a) Face Coverings  (b) Vaccination Coverage  (c) Removed Cases  (d) Delta Variant

(e) Changes in mobility to Workplaces  (f) Changes in mobility to Groceries and Pharmacies  (g) Changes in mobility to Retail and Recreation  (h) Changes in mobility to Parks
Results

Feature importance of the RF model

New York (NY)  
King (WA)  
Dallas (TX)

Los Angeles (CA)  
Miami Dade (FL)  
Hennepin (MN)

- Government Policy
- Human Mobility
- Delta Variant
- Removed Cases
- Vaccination

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Results

Random Forest model

Random forest (RF) is the best-performing model. The figure shows the feature importance in each of the local RF models for the 1362 selected counties.
Results

GWR model

- The GWR modeling is a cross-sectional study to investigate the relationship. It can be performed on data of any time slice during the study period.

- Reported here are the results for June 1, 2020.

Spatial distribution of coefficients of the GWR model
Conclusions

Findings and contributions

• The temporal change of $R^e$ in a place is positively associated with changes in human mobility and negatively associated with government intervention restrictions.

• Most importantly, $R^e$ is significantly impacted by the depletion of the susceptible population.

• By modeling the relationships between $R^e$ and local context factors, local policymakers and practitioners can better understand the effectiveness of various intervention policies.
Conclusions

Limitations and future work

• It is unknown whether different spatial scales may lead to other findings.

• The current research examines cross-sectional and temporal changes of $R^e$ separately.
Thank You

Questions, comments, and suggestions are welcome