Minimizing the Meal Gap: Pop-up Market Placement for Fair Accessibility in Hunger-relief Operations

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Acknowledgement

Award# 2125600
Serving Households in AReas with food Insecurity with a Network for Good: SHARING

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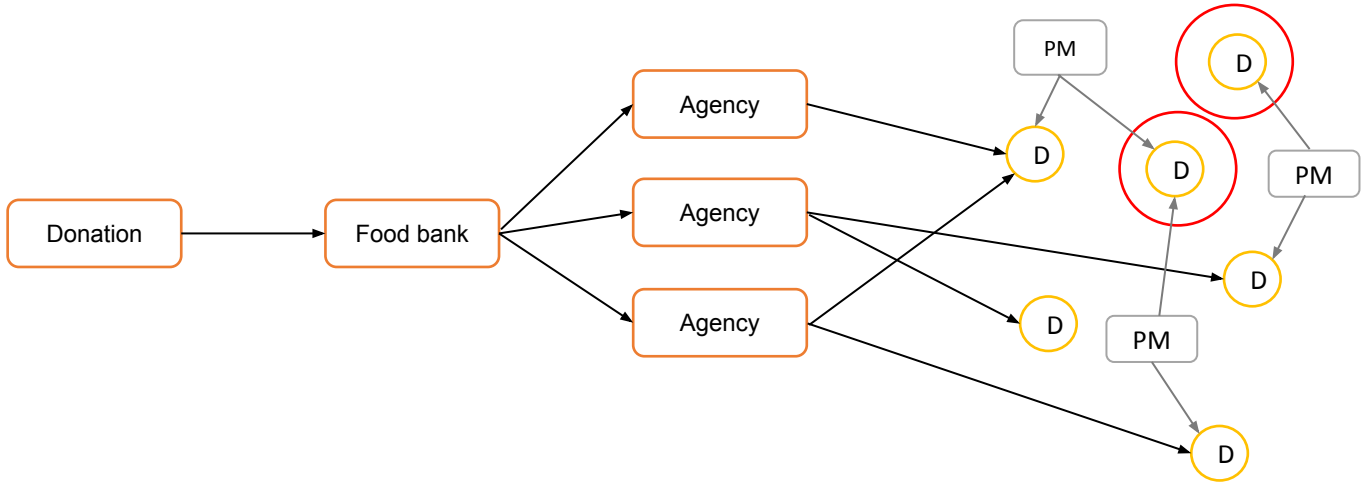
Food Insecurity

Lack of consistent access to enough food for every person in a household to live an active, healthy life.

More than **44 million** people, including **9 million** children, experience food insecurity in the United States [1].

https://www.feedingamerica.org/hunger-in-america

Hunger-relief Operations



D Food insecure neighborhood

PM- Pop up market

Pop up Markets

- **Distributions are directly facilitated by the food bank.**
- **Walk-up, with volunteers stocking tables from pallets of food.**
- **Provide additional support in places that have barriers to accessing pantries.**

https://foodbankcenc.org/pop-up-markets-fill-the-gaps/

Research Quetions

- Given known location of existing pantries and their operation schedules, how to optimally locate pop up markets with fair access to food insecure neighbourhoods?

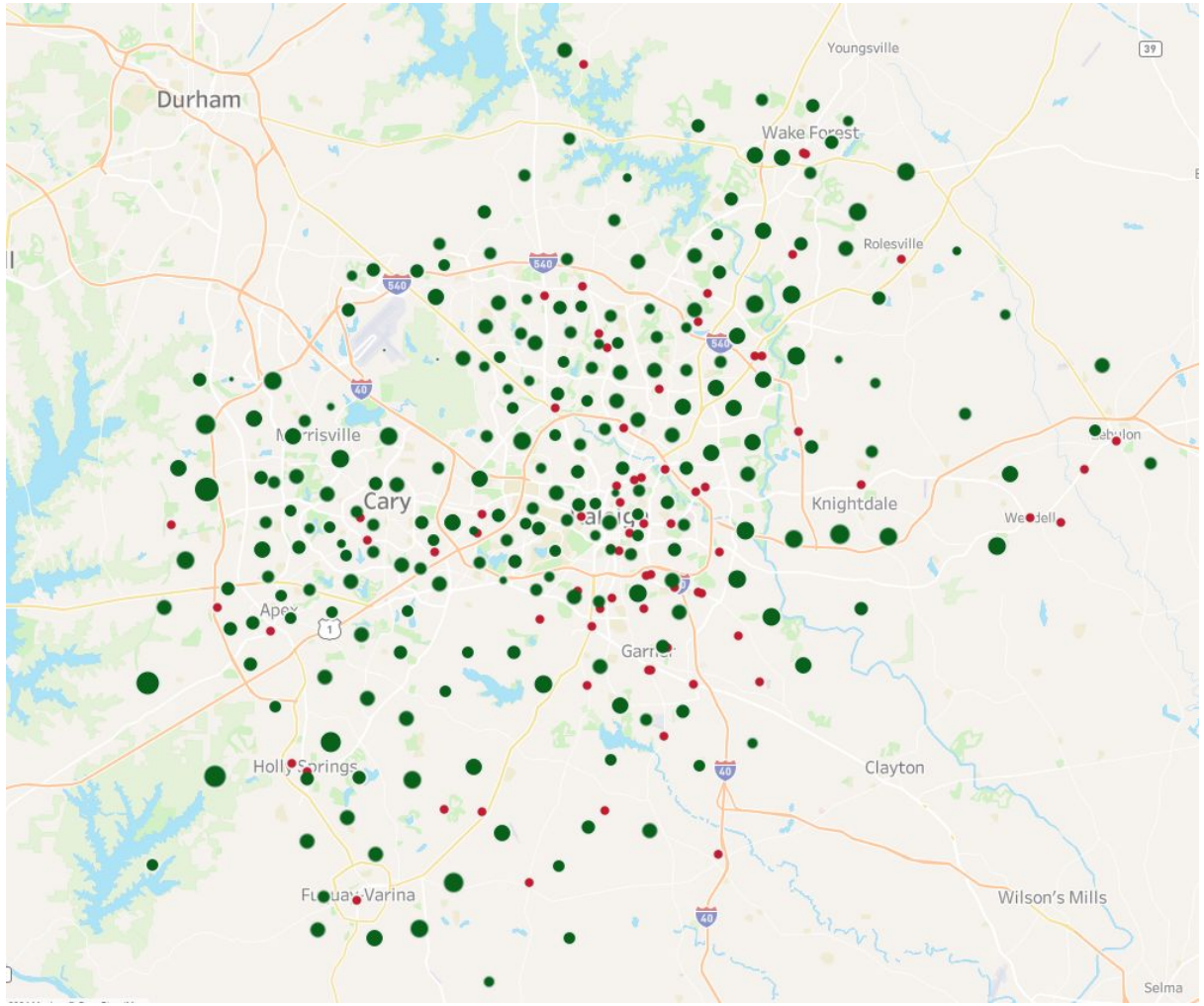
- Given that pop-up markets travel from a central foodbank in a region, how to optimize their opening costs?

Objective

- To find optimal location of pop-up markets in a network considering fairness in accessibility by food-insecure neighbourhoods
- To develop an optimal allocation plan that is equitable
- To optimize food bank's total operating costs for opening pop up markets

- How food insecurity rate in census tracts can be estimated?

In Wake County: 230 tracts
Food pantries: 73

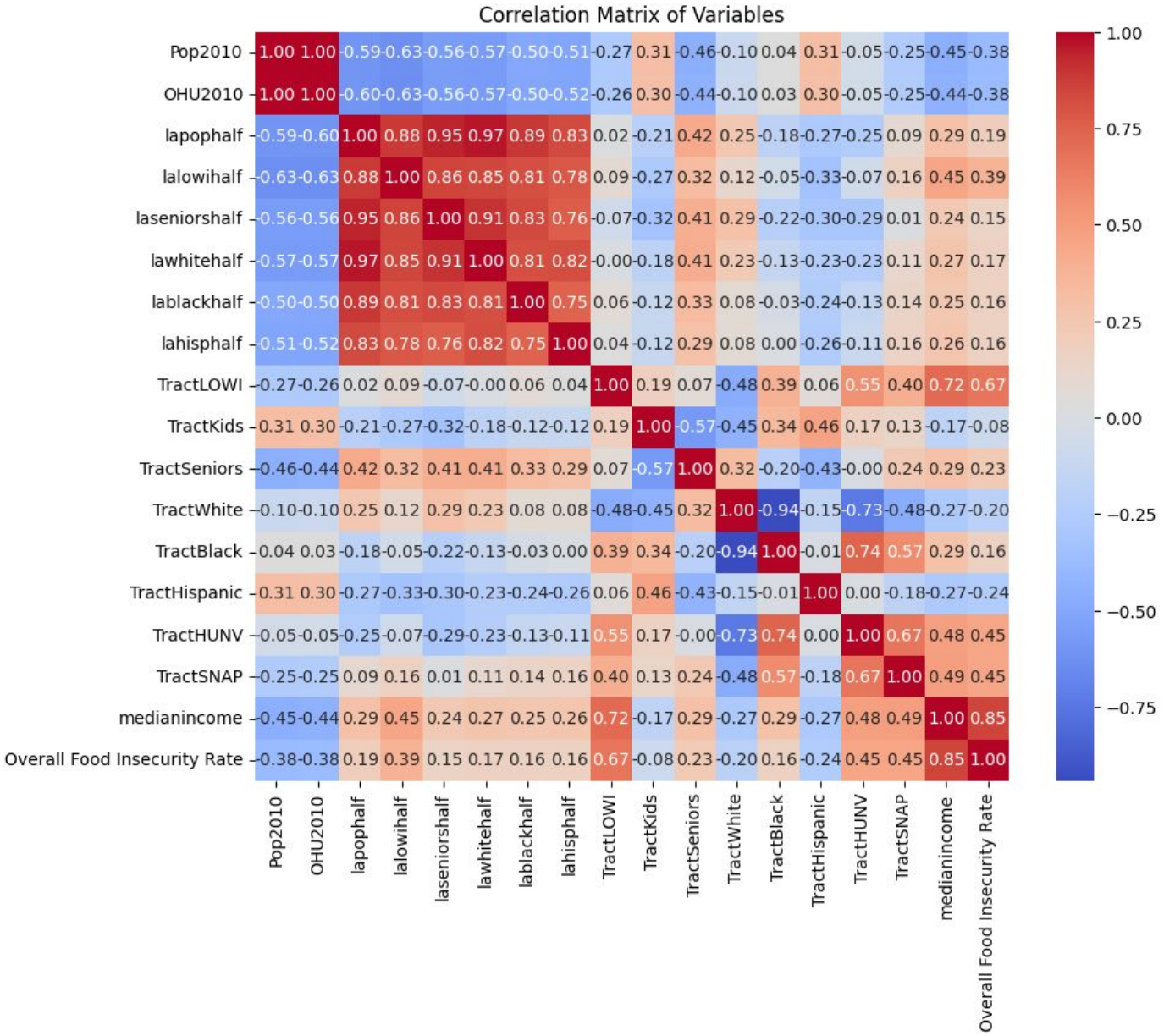


Data

Explore census tract level data on food access

Variable name	Description
Pop2010	Population count from 2010 census
OHU2010	Occupied housing unit count from 2010 census
lapophalf	Total population, low-income population, seniors, White, Black, and Hispanic population count beyond 1/2 mile from supermarket
lalowihalf	
laseniorshalf	
lawhitehalf	
lablackhalf	
lahisphalf	
TractLOWI	Total count of low-income, children, seniors, White, Black, Hispanic population in tract
TractKids	
TractSeniors	
TractWhite	
TractBlack	
TractHispanic	
TractHUNV	Total count of housing units without a vehicle in tract
TractSNAP	Total count of housing units receiving SNAP benefits in tract
MedianIncome	Tract median family income
OverallFoodinsecurityRate	Overall food insecurity rate

Data



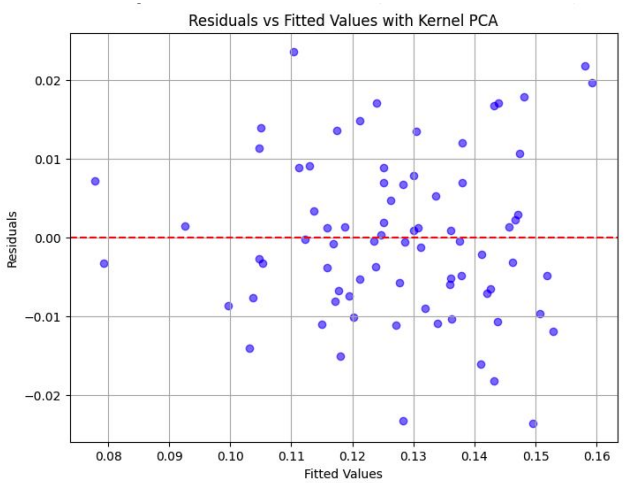
Develop machine learning model to estimate census tract level food insecurity rate

Multicollinearity

Develop machine learning model to estimate census tract level food insecurity rate

Regression with principal component

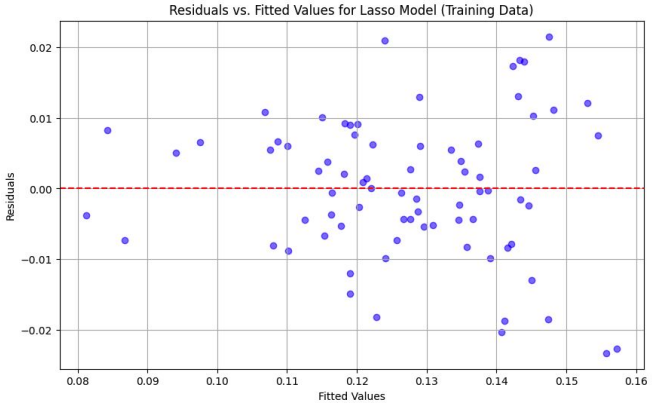
Model	R^2	MSPE	RMSE
Linear kernel	0.761	0.0001	0.0103
RBF kernel	0.727	0.0001	0.0111
Polynomial Kernel	0.466	0.0002	0.0155
Sigmoid Kernel	0.712	0.0001	0.0113



Linear Kernel

Regression with interaction and polynomial terms

Model	R^2	MSPE	RMSE
Lasso	**0.762**	0.0001	0.0103
Ridge	0.733	0.0001	0.0109
ElasticNet	0.751	0.0001	0.0106

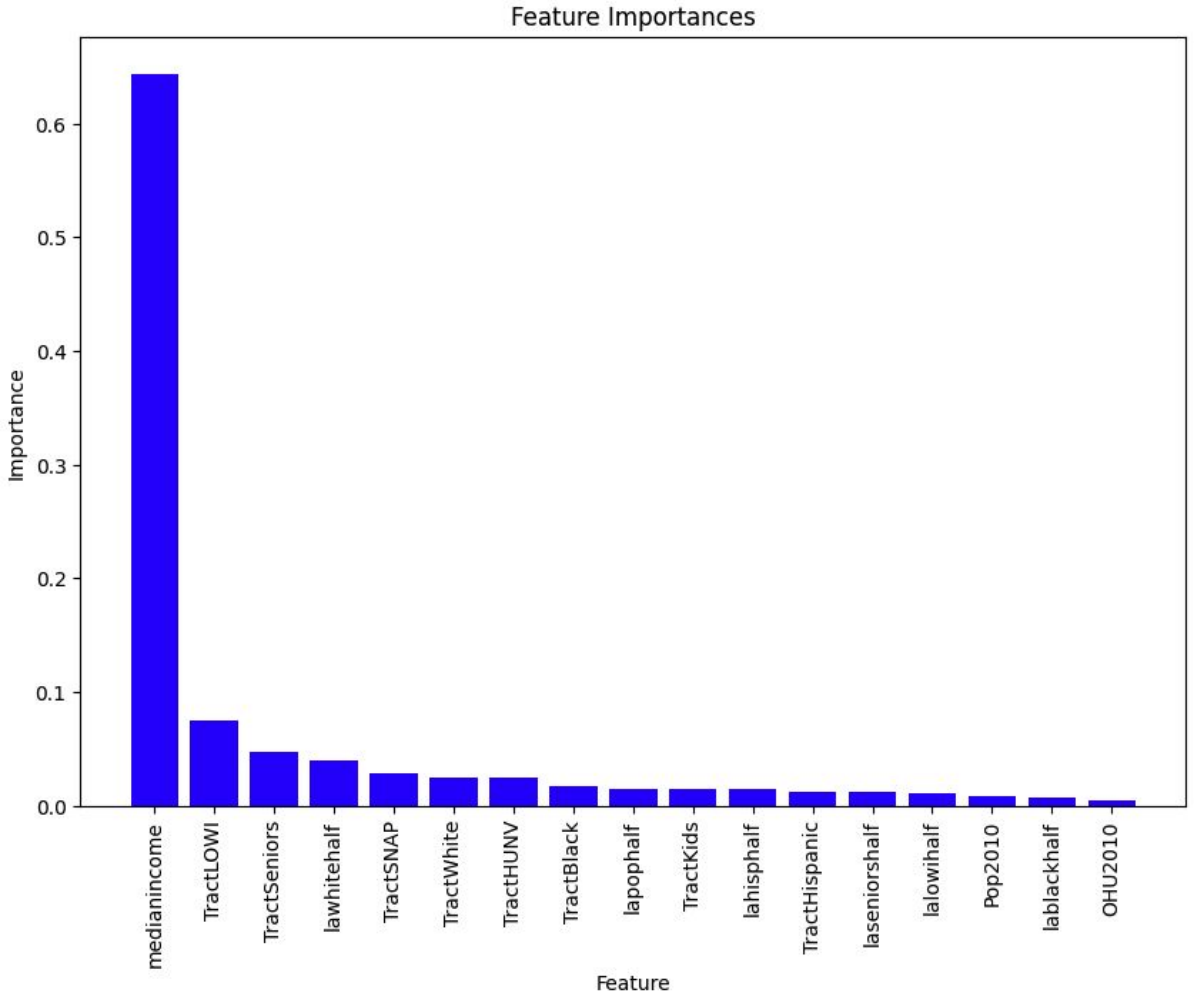


Lasso model

Heteroscedasticity

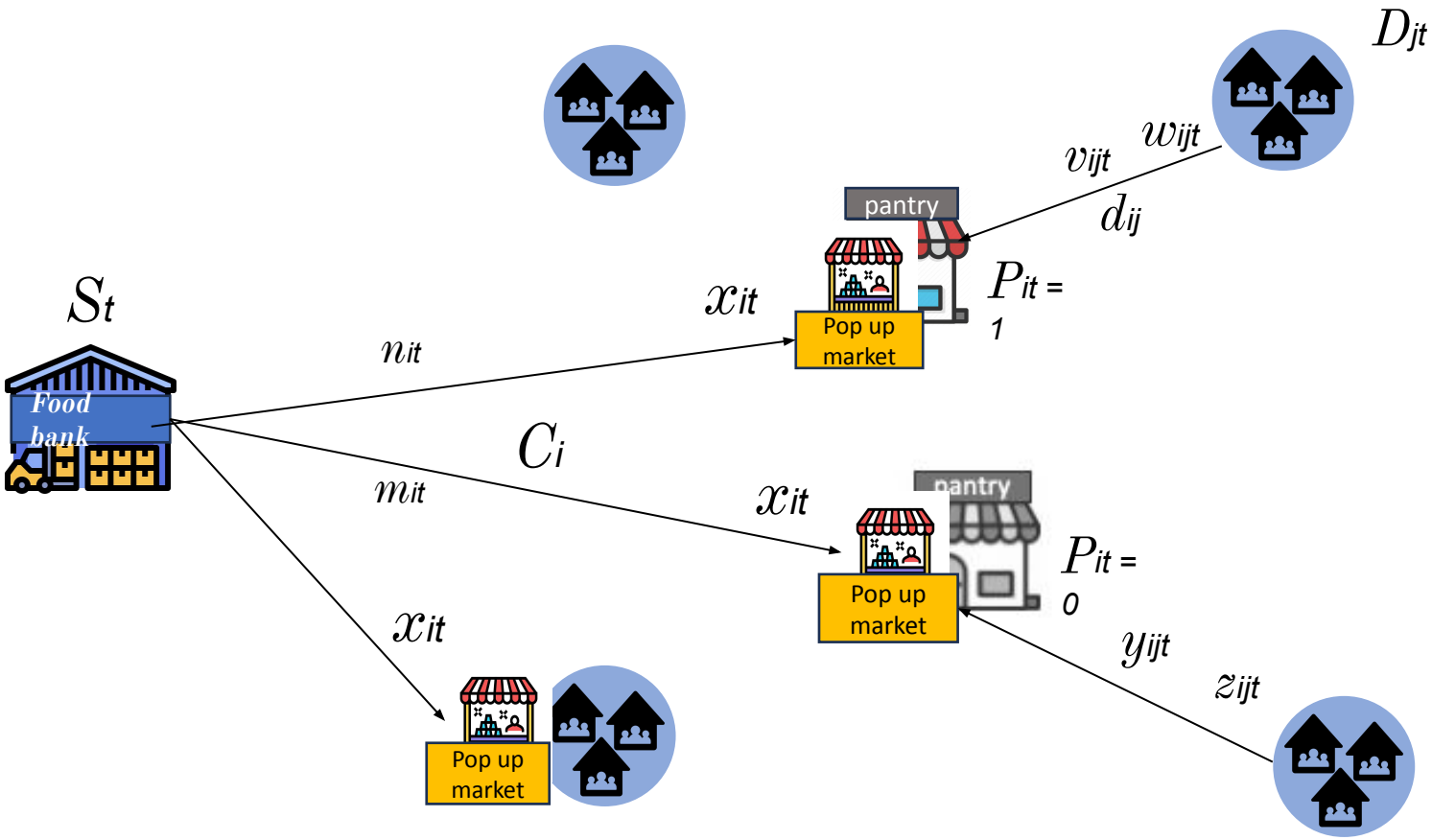
Tree-based models:

Develop machine learning model to estimate census tract level food insecurity rate



Model	R^2	MSPE	RMSE
RandomForrest	0.713	0.0001	0.0114
GradientBoosting	0.766	0.0001	0.0103
AdaBoosting	**0.780**	0.0001	0.0103
ExtraTrees	0.711	0.0001	0.0114

$t \in T$


D_{jt}
w_{ijt}
v_{ijt}
d_{ij}
pantry
P_{it} = 1
Pop up market
S_t
x_{it}
n_{it}
Food bank
C_i
m_{it}
x_{it}
pantry
P_{it} = 0
Pop up market
x_{it}
y_{ijt}
z_{ijt}
Pop up market

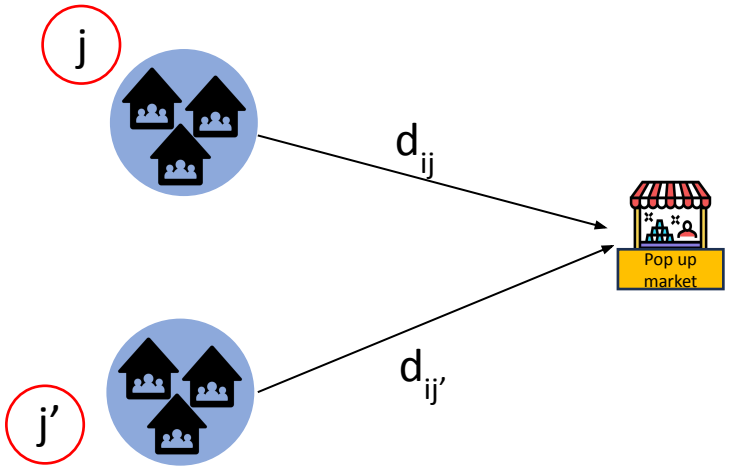
Formulation:

Model

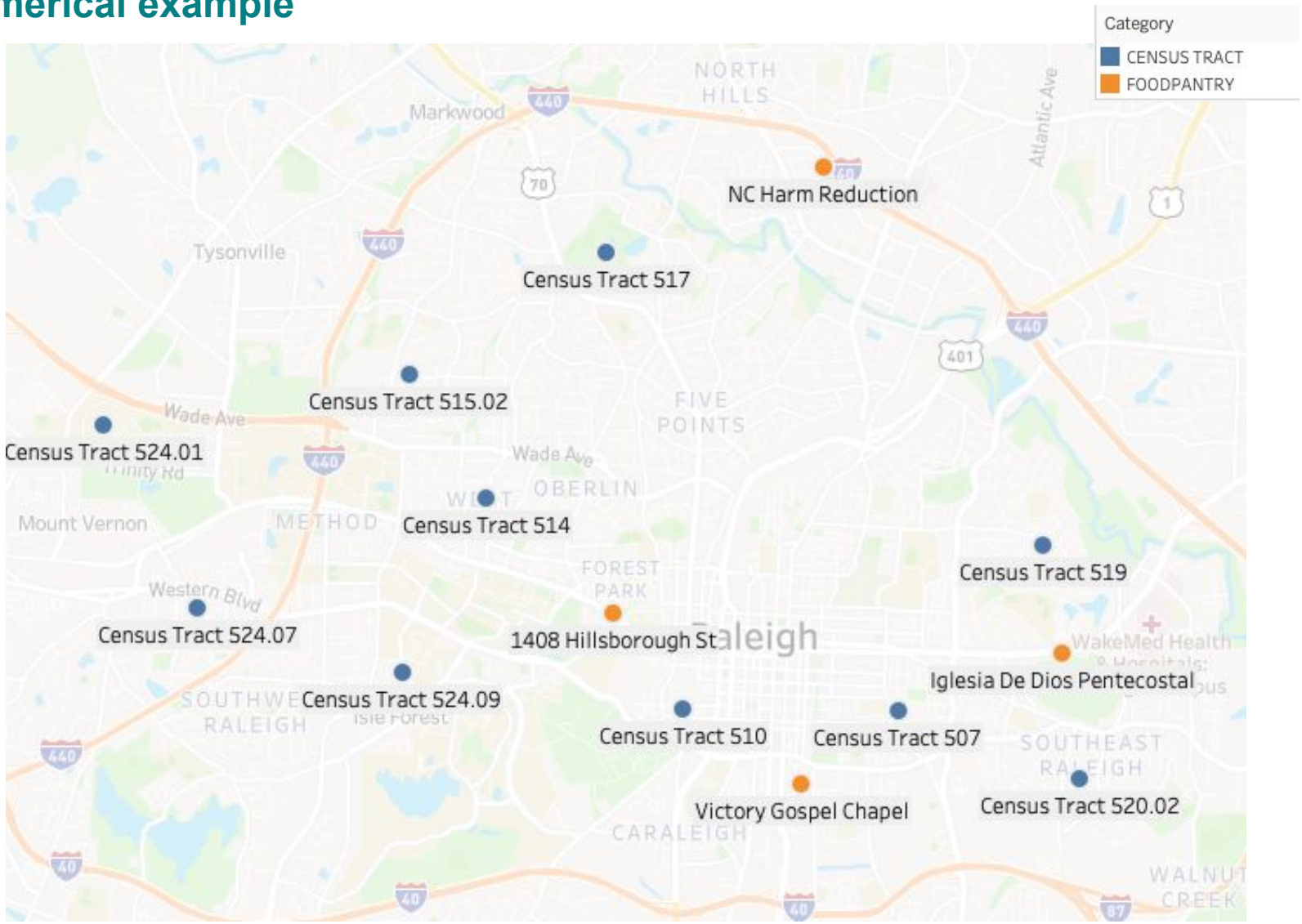
Fairness Constraints

Fair access

The difference in the ratio of distance traveled by a pair of census tracts



Numerical example



10 census tracts, 4 pantries

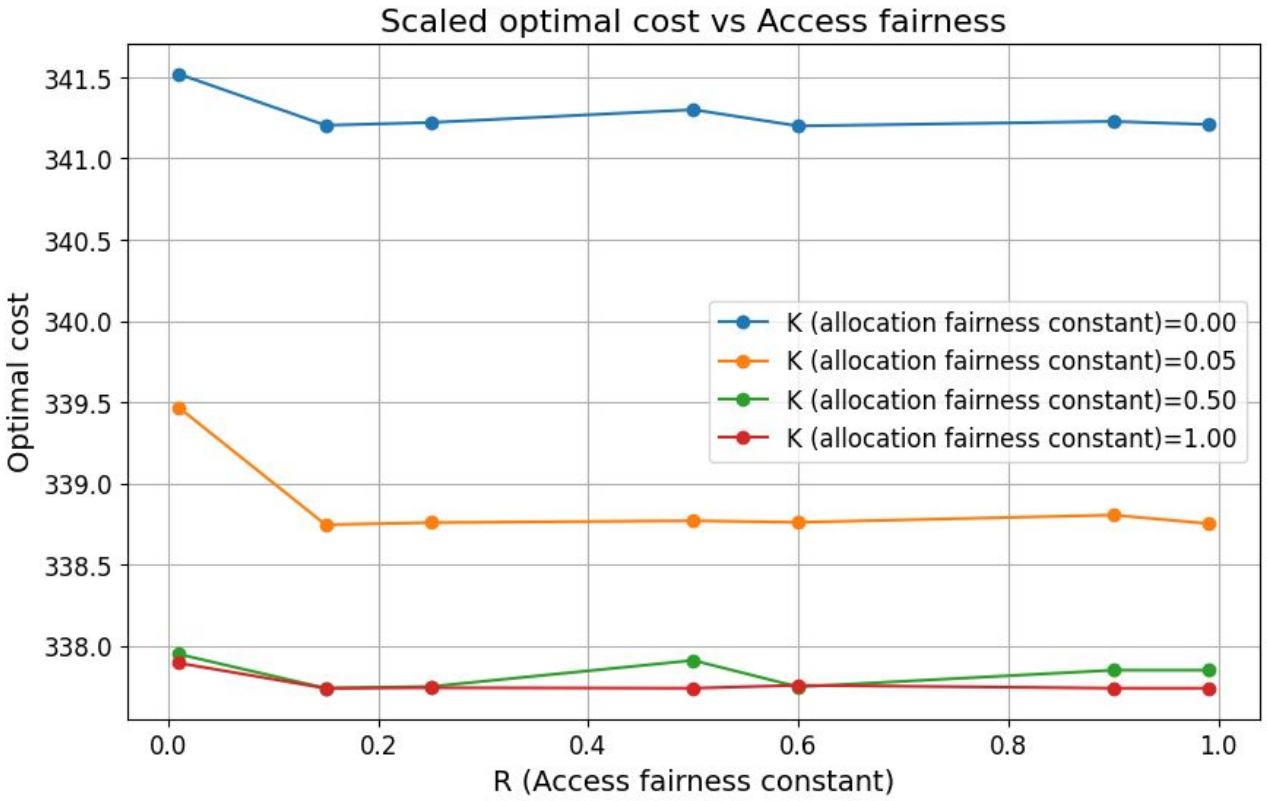
Results

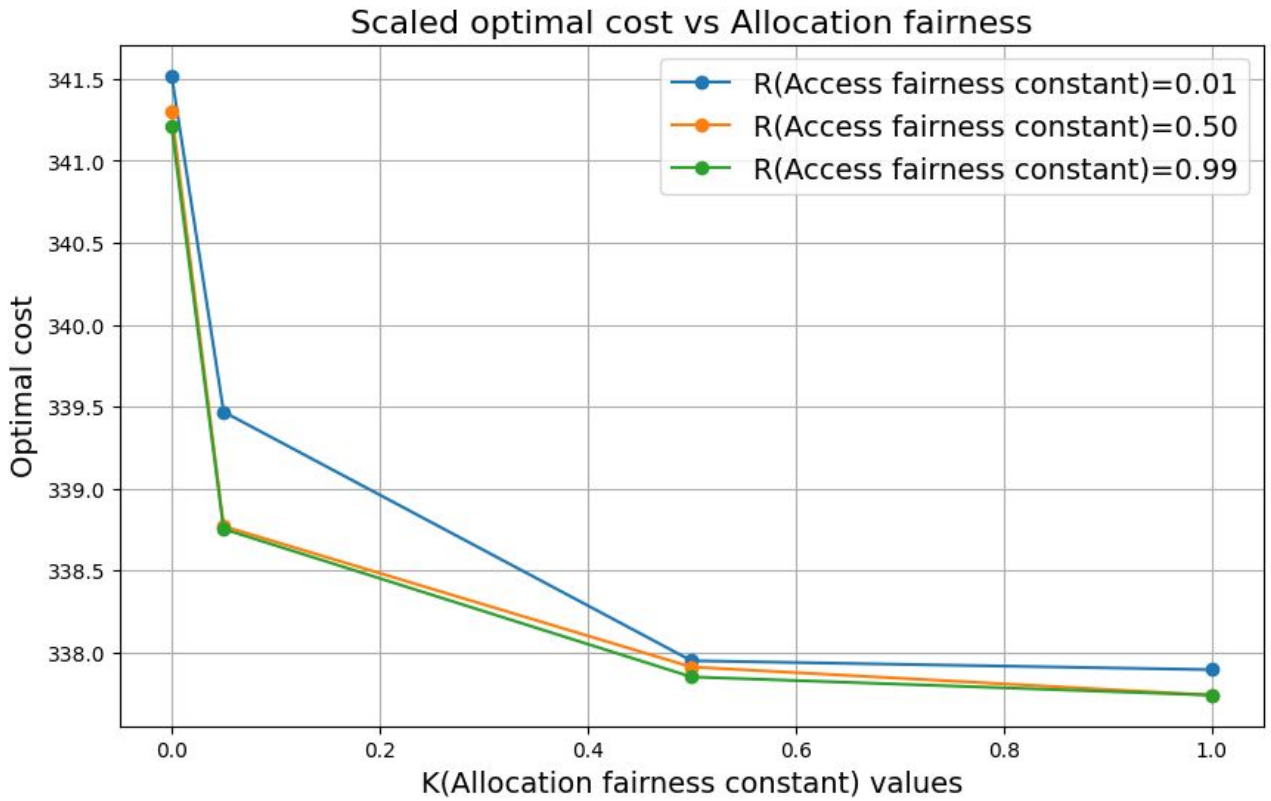
	Name	Type	Latitude.1	Longitude.1
0	Census Tract 507	CENSUS TRACT	35.773924	-78.620733
1	Census Tract 510	CENSUS TRACT	35.774008	-78.648169
2	Census Tract 514	CENSUS TRACT	35.795958	-78.673180
3	Census Tract 515.02	CENSUS TRACT	35.808707	-78.683138
4	Census Tract 517	CENSUS TRACT	35.821340	-78.657951
5	Census Tract 519	CENSUS TRACT	35.790991	-78.602144
6	Census Tract 520.02	CENSUS TRACT	35.766849	-78.597549
7	Census Tract 524.01	CENSUS TRACT	35.803375	-78.722109
8	Census Tract 524.07	CENSUS TRACT	35.784601	-78.710068
9	Census Tract 524.09	CENSUS TRACT	35.777891	-78.684019
10	1408 Hillsborough St	FOODPANTRY	35.784082	-78.656971
11	Victory Gospel Chapel	FOODPANTRY	35.766300	-78.633016
12	NC Harm Reduction	FOODPANTRY	35.830042	-78.630174
13	Iglesia De Dios Pentecostal	FOODPANTRY	35.779860	-78.599787

Numerical example

Results

Impact on optimal cost

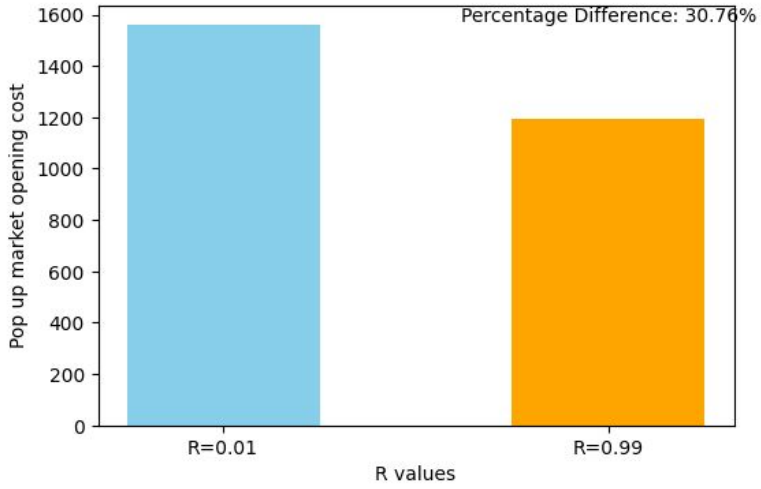


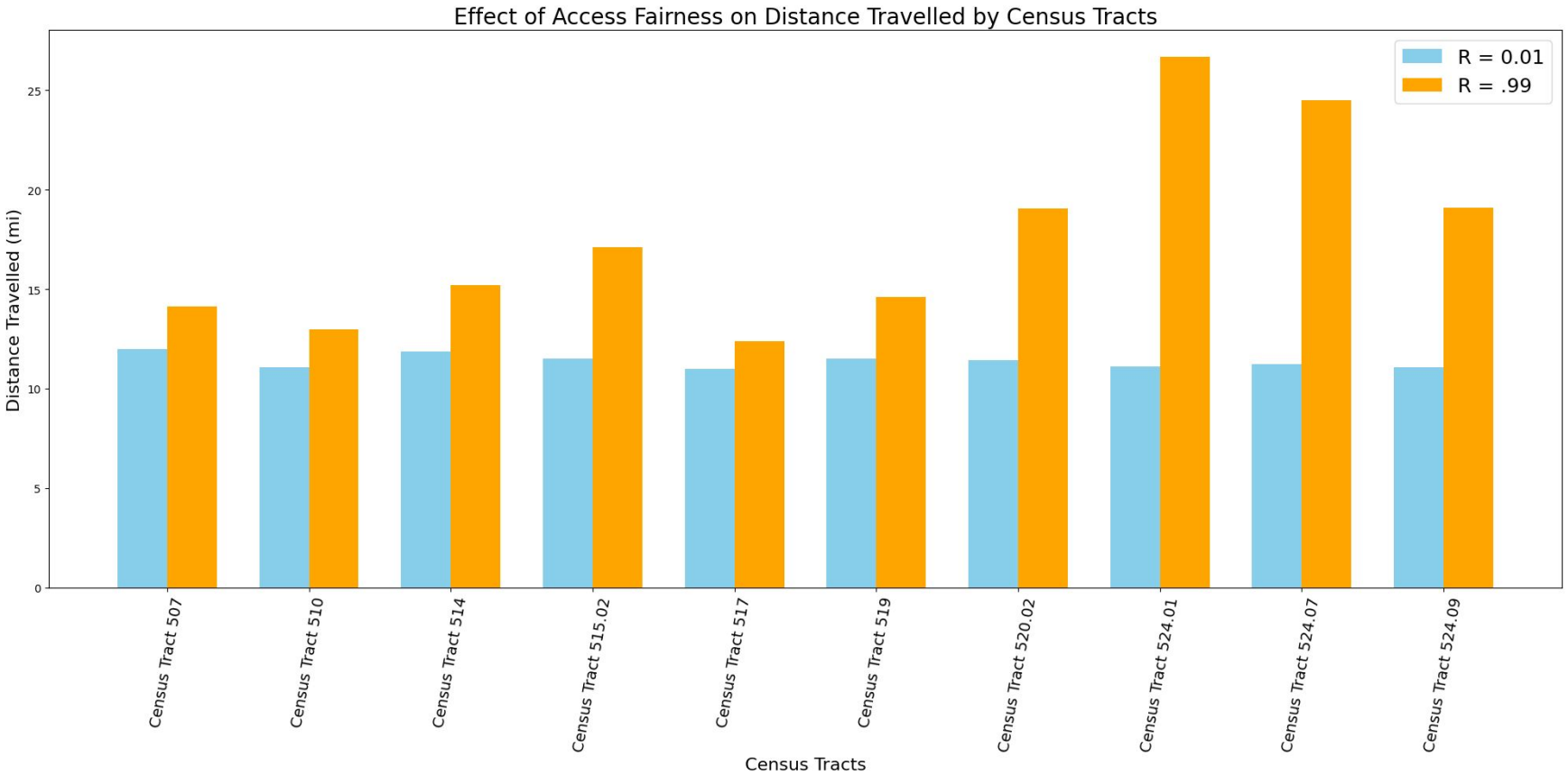


Numerical example

Discussion

Impact of access fairness:

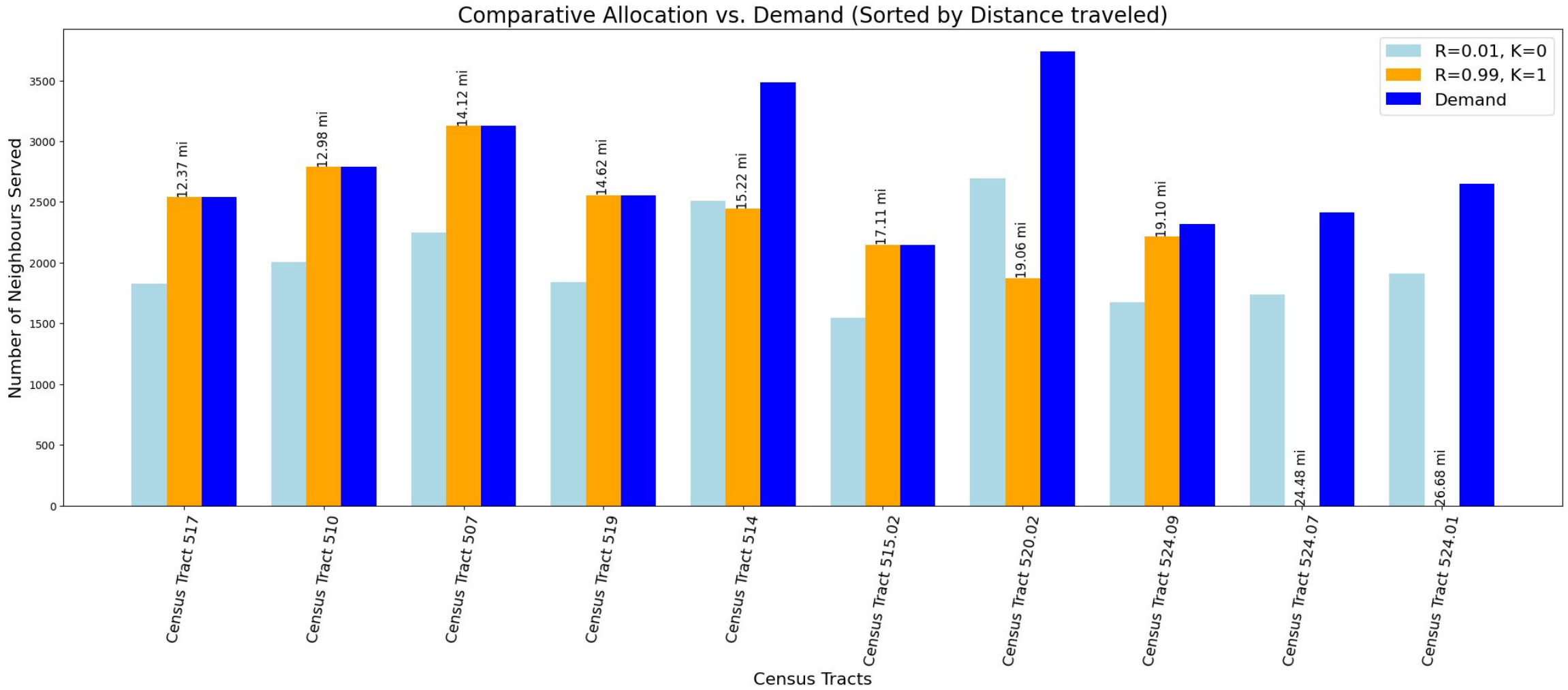




Numerical example

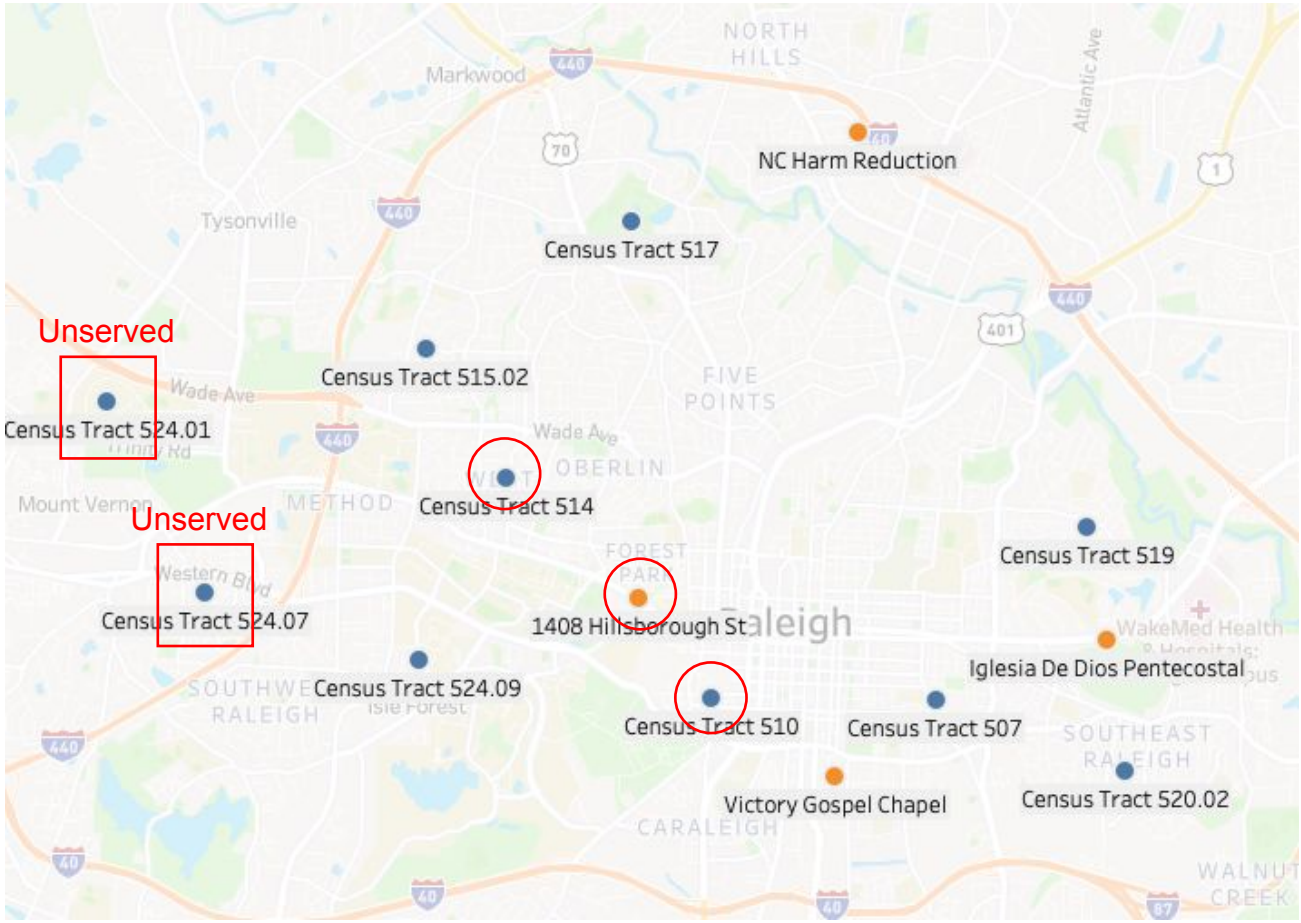
Impact of combined access and allocation fairness:

Discussion



Conclusion

- Near-perfect fairness in access and allocation increases Foodbank's operating costs.
- For foodbank decision-makers-
  - Emphasis on fairness: The optimal location of the pop up markets ensures all census tracts are served
  - Emphasis on operating cost: The optimal location of the pop up reduces opening costs but sacrifices allocation to census tracts far from facilities



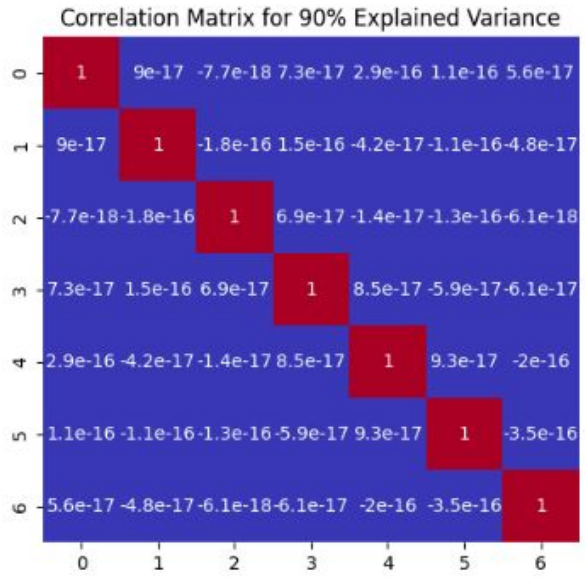
Future work

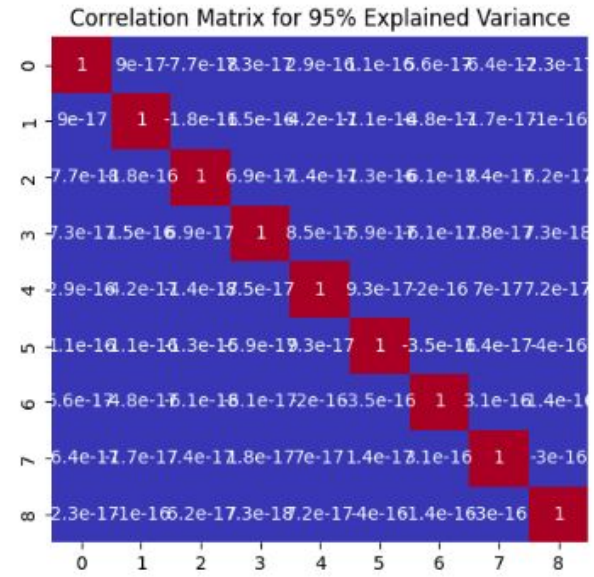
- Incorporate uncertainty in supply, demand, and disruption in allocation.
- Use a larger network to see the impact on results.

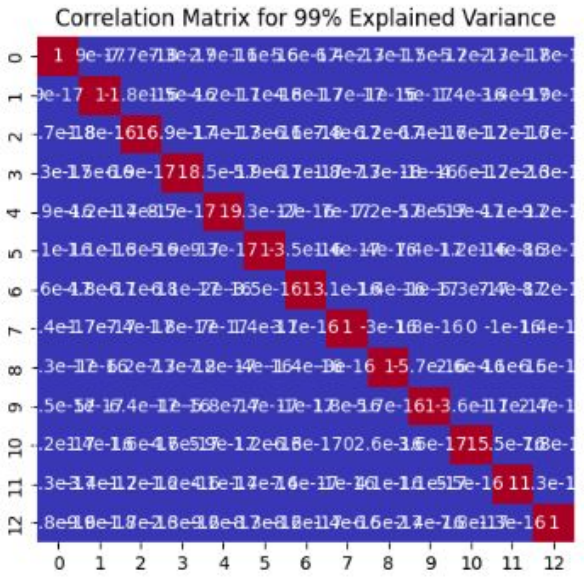
Questions

PCA analysis

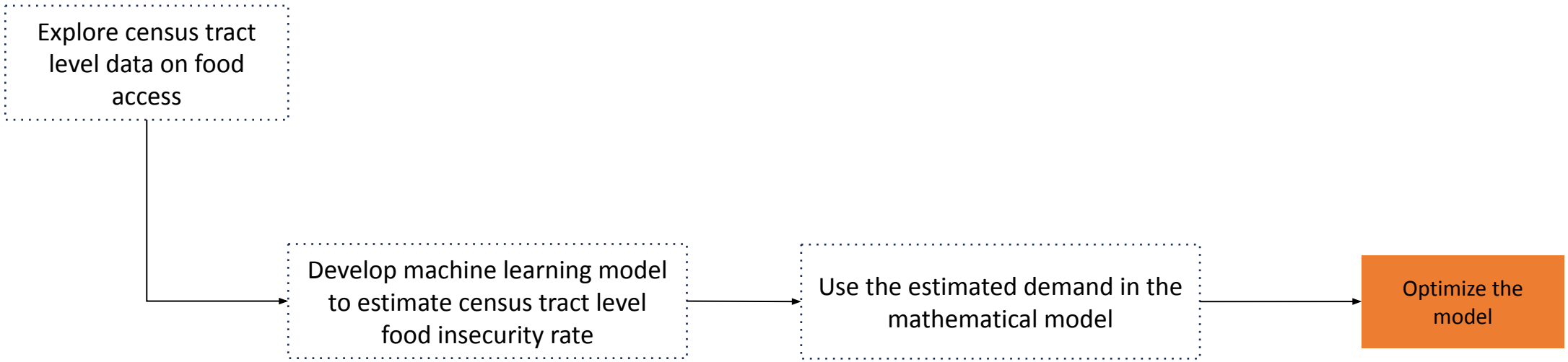
Number of components with 90% explained variance: 7
Performance with 90% explained variance: R^2=0.7576712833542005, MSE=0.00010937748954524807, MSPE=0.010458369354026853
Number of components with 95% explained variance: 9
Performance with 95% explained variance: R^2=0.7618096913096813, MSE=0.00010750957773046223, MSPE=0.010368682545553327
Number of components with 99% explained variance: 13
Performance with 99% explained variance: R^2=0.7446237881527399, MSE=0.00011526660697937935, MSPE=0.010736228713071427







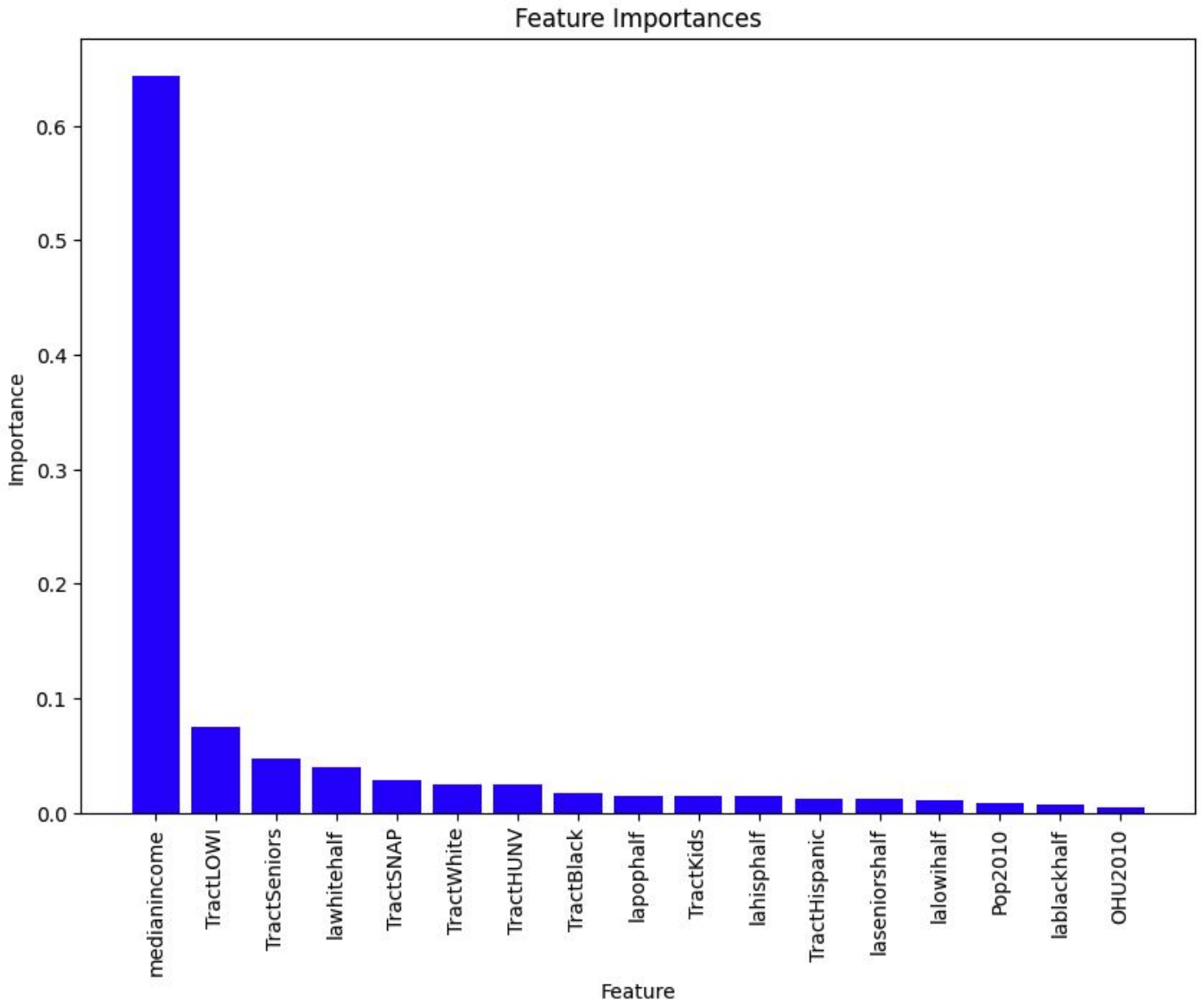
Framework


Explore census tract level data on food access
Develop machine learning model to estimate census tract level food insecurity rate
Use the estimated demand in the mathematical model
Optimize the model

Assumptions:

Model

- Pop up markets travel to one location for a period.
- Pop up markets can be replenished for each period up to their total capacity based on available supply at food bank.
- Existing pantries can carry over the inventory to the next period.
- The undistributed food from pop-up markets can be added to the total supply of the foodbank in the next period.



Feature importances:
medianincome: 0.6441
TractLOWI: 0.0748
TractSeniors: 0.0477
lawhitehalf: 0.0397
TractSNAP: 0.0282
TractWhite: 0.0251
TractHUNV: 0.0245
TractBlack: 0.0173
lapophalf: 0.0147
TractKids: 0.0145
lahisphalf: 0.0144
TractHispanic: 0.0127
laseniorshalf: 0.0118
lalowihalf: 0.0108
Pop2010: 0.0083
lablackhalf: 0.0072
OHU2010: 0.0042

Lasso model coefficients:

Pop2010: -0.0 OHU2010: -0.0 lapophalf: -0.0 lalowihalf: 0.0 laseniorshalf: -0.0 lawhitehalf: -0.0 lablackhalf: -0.0 lahisphalf: -0.0 TractLOWI: 0.0 TractKids: 0.0 TractSeniors: 0.0 TractWhite: -0.0 TractBlack: -0.0 TractHispanic: -0.0 TractHUNV: 0.0 TractSNAP: 0.0 medianincome: 0.04804439289390823 Pop2010^2: -0.0 Pop2010 OHU2010: -0.0 Pop2010 lapophalf: -0.0 Pop2010 lalowihalf: -0.0 Pop2010 laseniorshalf: -0.0 Pop2010 lawhitehalf: -0.0 Pop2010 lablackhalf: -0.0 Pop2010 lahisphalf: -0.0 Pop2010 TractLOWI: -0.0 Pop2010 TractKids: -0.0 Pop2010 TractSeniors: -0.0 Pop2010 TractWhite: -0.0 Pop2010 TractBlack: -0.0 Pop2010 TractHispanic: -0.0 Pop2010 TractHUNV: -0.0 Pop2010 TractSNAP: -0.0 Pop2010 medianincome: 0.0 OHU2010^2: -0.0036459331494641907 OHU2010 lapophalf: -0.0 OHU2010 lalowihalf: -0.0 OHU2010 laseniorshalf: -0.0 OHU2010 lawhitehalf: -0.0 OHU2010 lablackhalf: -0.0 OHU2010 lahisphalf: -0.0 OHU2010 TractLOWI: -0.0 OHU2010 TractKids: -0.0 OHU2010 TractSeniors: -0.0 OHU2010 TractWhite: -0.0 OHU2010 TractBlack: -0.0 OHU2010 TractHispanic: -0.0 OHU2010 TractHUNV: -0.0 OHU2010 TractSNAP: -0.0 OHU2010 medianincome: 0.0 lapophalf^2: -0.0 lapophalf lalowihalf: 0.0 lapophalf laseniorshalf: -0.0 lapophalf lawhitehalf: -0.0 lapophalf lablackhalf: -0.0 lapophalf lahisphalf: -0.0 lapophalf TractLOWI: 0.0 lapophalf TractKids: 0.0 lapophalf TractSeniors: 0.0 lapophalf TractWhite: -0.0 lapophalf TractBlack: -0.0 lapophalf TractHispanic: -0.0 lapophalf TractHUNV: 0.0 lapophalf TractSNAP: 0.0 lapophalf medianincome: 0.0 lalowihalf^2: 0.007027512166416194 lalowihalf laseniorshalf: 0.0 lalowihalf lawhitehalf: 0.0 lalowihalf lablackhalf: 0.0 lalowihalf lahisphalf: 0.0 lalowihalf TractLOWI: 0.0 lalowihalf TractKids: 0.0 lalowihalf TractSeniors: 0.0 lalowihalf TractWhite: 0.0 lalowihalf TractBlack: -0.0 lalowihalf TractHispanic: -0.0 lalowihalf TractHUNV: 0.0 lalowihalf TractSNAP: 0.0 lalowihalf medianincome: 0.0 laseniorshalf^2: -0.004592926975291603 laseniorshalf lawhitehalf: -0.0 laseniorshalf lablackhalf: -0.0 laseniorshalf lahisphalf: -0.0 laseniorshalf TractLOWI: 0.0 laseniorshalf TractKids: 0.0 laseniorshalf TractSeniors: 0.0 laseniorshalf TractWhite: -0.0 laseniorshalf TractBlack: -0.0 laseniorshalf TractHispanic: -0.0 laseniorshalf TractHUNV: 0.0 laseniorshalf TractSNAP: 0.0 laseniorshalf medianincome: 0.0 lawhitehalf^2: -0.0 lawhitehalf lablackhalf: -0.0 lawhitehalf lahisphalf: -0.0 lawhitehalf TractLOWI: 0.0 lawhitehalf TractKids: 0.0 lawhitehalf TractSeniors: 0.0 lawhitehalf TractWhite: -0.0 lawhitehalf TractBlack: -0.0 lawhitehalf TractHispanic: -0.0 lawhitehalf TractHUNV: 0.0 lawhitehalf TractSNAP: 0.0 lawhitehalf medianincome: 0.0 lablackhalf^2: -0.0 lablackhalf lahisphalf: -0.0 lablackhalf TractLOWI: 0.0 lablackhalf TractKids: 0.0 lablackhalf TractSeniors: 0.0 lablackhalf TractWhite: -0.0 lablackhalf TractBlack: -0.007791404750052154 lablackhalf TractHispanic: -0.0 lablackhalf TractHUNV: 0.0 lablackhalf TractSNAP: 0.0 lablackhalf medianincome: 0.0 lahisphalf^2: -0.01036047015755405 lahisphalf TractLOWI: 0.0 lahisphalf TractKids: 0.0 lahisphalf TractSeniors: 0.0 lahisphalf TractWhite: -0.0 lahisphalf TractBlack: -0.0 lahisphalf TractHispanic: -0.0 lahisphalf TractHUNV: 0.0 lahisphalf TractSNAP: 0.0 lahisphalf medianincome: 0.0 TractLOWI^2: 0.0 TractLOWI TractKids: 0.0 TractLOWI TractSeniors: 0.0 TractLOWI TractWhite: 0.0 TractLOWI TractBlack: -0.0 TractLOWI TractHispanic: -0.0 TractLOWI TractHUNV: 0.0 TractLOWI TractSNAP: 0.0 TractLOWI medianincome: 0.023278175464559552 TractKids^2: 0.0 TractKids TractSeniors: 0.0 TractKids TractWhite: 0.0 TractKids TractBlack: -0.0 TractKids TractHispanic: -0.0 TractKids TractHUNV: 0.0 TractKids TractSNAP: 0.0 TractKids medianincome: 0.0 TractSeniors^2: 0.0 TractSeniors TractWhite: 0.0 TractSeniors TractBlack: -0.0 TractSeniors TractHispanic: -0.0 TractSeniors TractHUNV: 0.0 TractSeniors TractSNAP: 0.0 TractSeniors medianincome: 0.0 TractWhite^2: -0.0 TractWhite TractBlack: -0.0 TractWhite TractHispanic: -0.0 TractWhite TractHUNV: 0.0 TractWhite TractSNAP: 0.0 TractWhite medianincome: 0.0 TractBlack^2: -0.0 TractBlack TractHispanic: -0.0 TractBlack TractHUNV: 0.0 TractBlack TractSNAP: 0.0 TractBlack medianincome: -0.0 TractHispanic^2: -0.0 TractHispanic TractHUNV: -0.0 TractHispanic TractSNAP: -0.0 TractHispanic medianincome: -0.0 TractHUNV^2: 0.0 TractHUNV TractSNAP: 0.0 TractHUNV medianincome: 0.0 TractSNAP^2: 0.0 TractSNAP medianincome: 0.0 medianincome^2: 0.016686519821013338

Fitting 5 folds for each of 36 candidates, totalling 180 fits
Best parameters for RandomForest: {'max_depth': 20, 'n_estimators': 50}
Fitting 5 folds for each of 120 candidates, totalling 600 fits
Best parameters for GradientBoosting: {'learning_rate': 0.2, 'max_depth': 3, 'n_estimators': 150}
Fitting 5 folds for each of 30 candidates, totalling 150 fits
Best parameters for AdaBoost: {'learning_rate': 0.05, 'n_estimators': 200}
Fitting 5 folds for each of 36 candidates, totalling 180 fits
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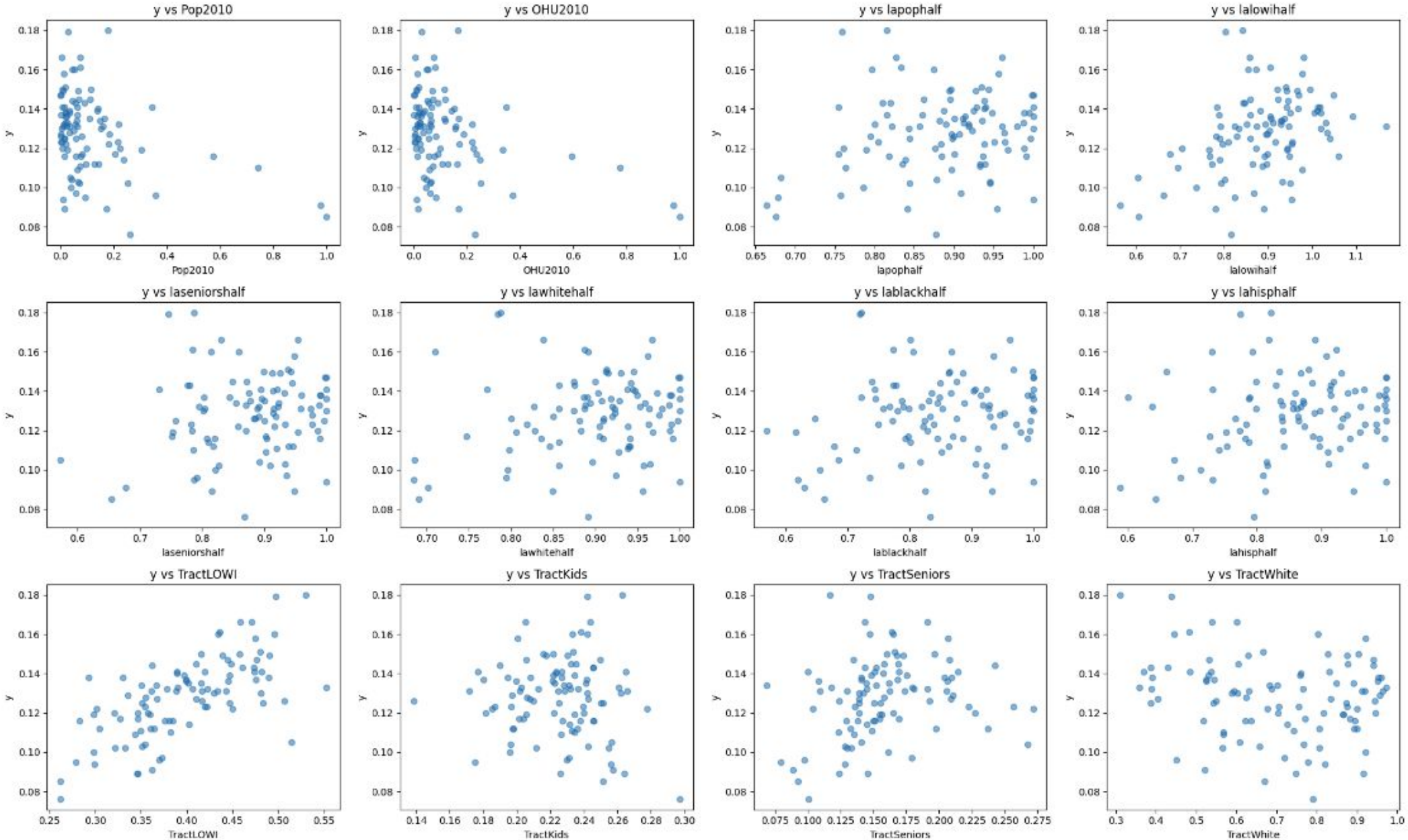
Best parameters for Bagging: {'n_estimators': 50}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Pop2010
y vs OHU2010
OHU2010
y vs lapophalf
lapophalf
y vs lalowihalf
lalowihalf
y vs laseniorshalf
laseniorshalf
y vs lawhitehalf
lawhitehalf
y vs lablackhalf
lablackhalf
y vs lahisphalf
lahisphalf
y vs TractLOWI
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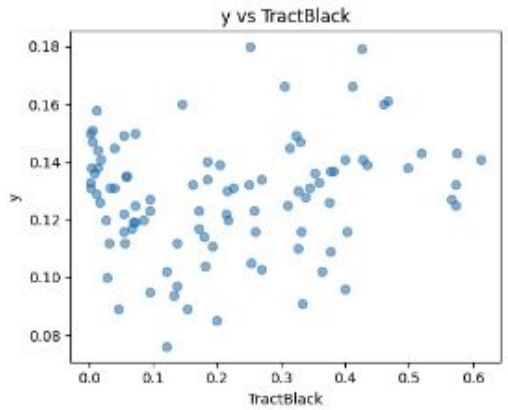
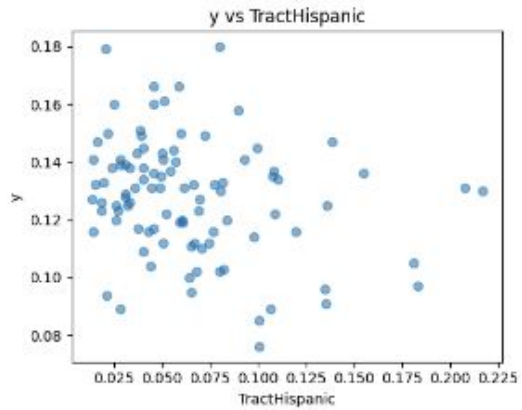
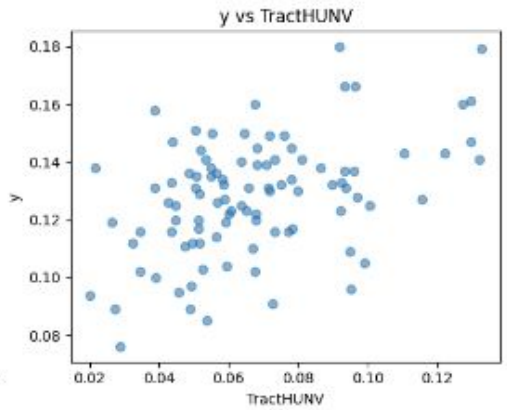
y vs TractSeniors
TractSeniors
y vs TractWhite
TractWhite
y


y vs TractBlack
y
TractBlack


y vs TractHispanic
y
TractHispanic


y vs TractHUNV
y
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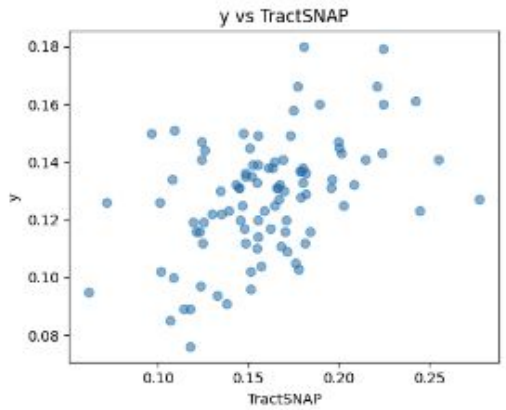
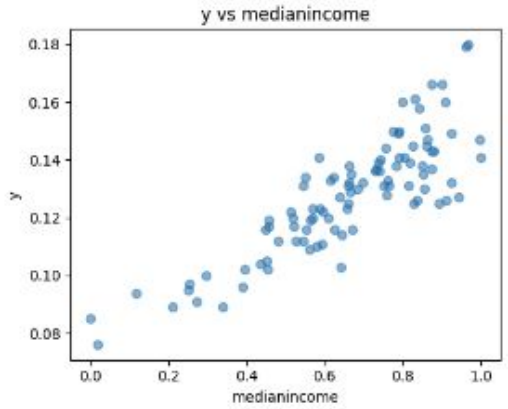
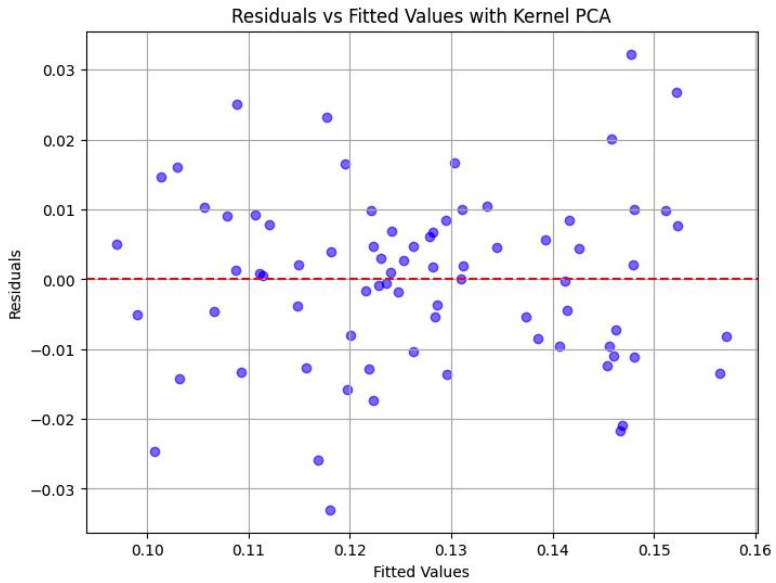
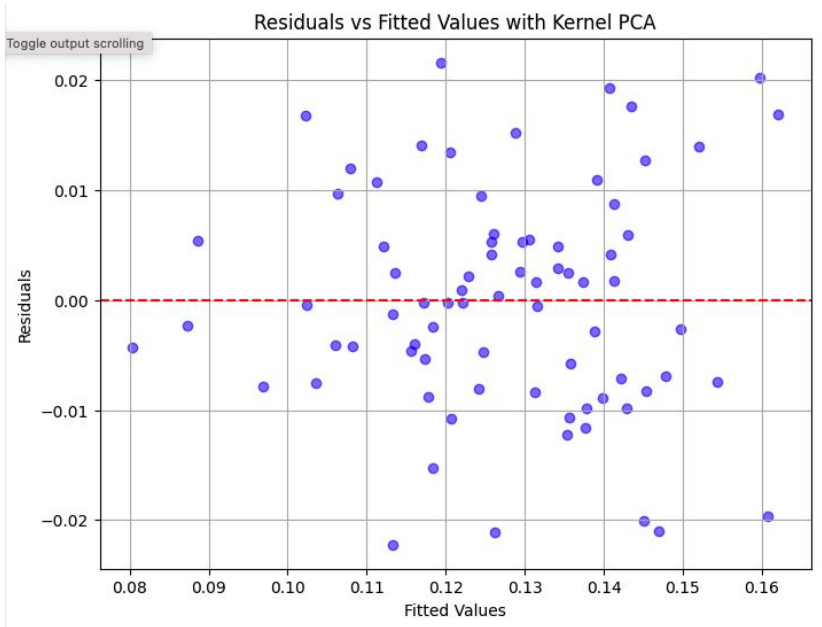

y vs TractSNAP
y
TractSNAP


y vs medianincome
y
medianincome


Residuals vs Fitted Values with Kernel PCA
Residuals
Fitted Values
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
0.10
0.11
0.12
0.13
0.14
0.15
0.16

RBF


Residuals vs Fitted Values with Kernel PCA
Toggle output scrolling
Residuals
Fitted Values
0.02
0.01
0.00
−0.01
−0.02
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16

Sigmoid