Urban Highway Removal: Evidence from Rochester

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Background and motivation

- During the mid-20th century, highways were built through urban areas
- Often for populations which never materialized
 - E.g. Rochester's population declined from 330,000 to 210,000
 - Cities are trying to attract young, working-age adults by offering improved amenities (Carlino & Saiz 2019, Glaeser et al. 2001)
- Old, in need of repair
 - As of 2018, \$852B is required to address repairs (FHWA)
- $\bullet \sim 30$ cities across the US are discussing the removal of these highways



Tradeoffs

Benefit

• Improve local amenities to attract young, working-age adults

Costs

- Capitalization of improved amenities into housing prices
- Increase traffic on other roads and greater congestion

Net effect depends on

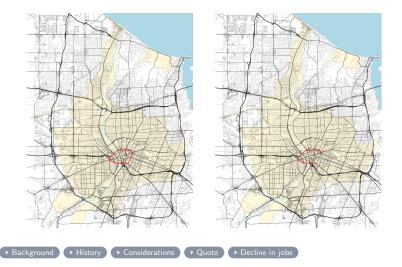
- change in amenities
- changes to commuting costs
- capitalization into housing prices
- preferences

Research question

What are the distributional consequences of removing an urban highway?

- demographic and socio-economic composition of the affected neighbourhoods
- cost of housing
- traffic and commuting costs

Inner Loop, Rochester, New York



Contribution

Introduction

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- 1. Document causal impact of removing an urban highway on local neighbourhoods
 - ightarrow Construct a panel
 - Commuting flows
 - Residential and employment shares
 - Property values and characteristics
 - Road-level info on speed, traffic, and road characteristics
 - Travel times between bilateral pairs of neighbourhoods
 - Neighbourhood characteristics (schools, libraries, cultural centers, consumption amenities, crime, topography, etc.)
- 2. Quantify the welfare effects using a quantitative spatial model
 - ightarrow Show how to apply demand estimation techniques to estimate the preference parameters of a QSMs
 - → Allows for more flexible demand system, more realistic substitution patterns and welfare results with fewer data requirements than standard approaches



Roadmap

- Introduction
- 2 Data & stylized facts
- 3 Model
- 4 Estimation
- 6 Results & welfare
- **6** Conclusion

Data

- Commuting flows and residential choices from LEHD Origin-Destination Employment Statistics (LODES)
- Property assessment data from Bureau of Assessment

 Matching process
- Speed, traffic and road characteristics from New York State Department of Transportation
- Travel times between pairs of neighbourhoods simulated from Google Maps API

 Details
- Topographic data from United States Geological Survey
- Neighbourhood amenities from Monroe County Department of Environmental Services
- Crime incidents from Rochester Police Department Details
- Standardized test scroes from New York State Education Department Details

Research Design

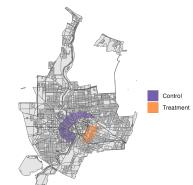
$$Y_{it} = \alpha + \sum_{k=T_0, k \neq -1}^{5} \beta_k \times treat_{ik} + \phi_i + \gamma_t + \epsilon_{it}$$

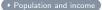
Treatment:

 Adjacent and within 1 km of removed highway

Control:

- Within 1 km of the Inner Loop
- At least 800m from treated neighbourhoods

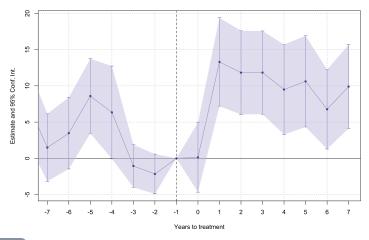






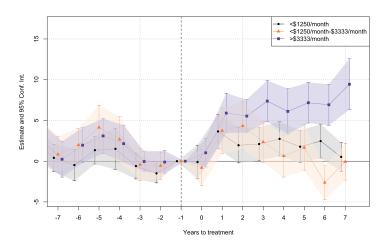


Impact on number of residents near the IL

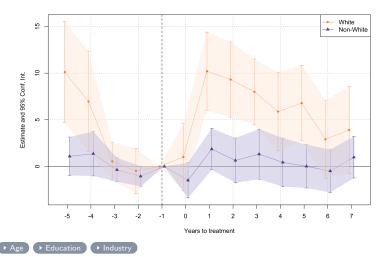




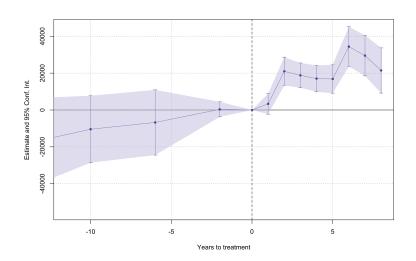
Effect is driven by an increase in higher-income residents



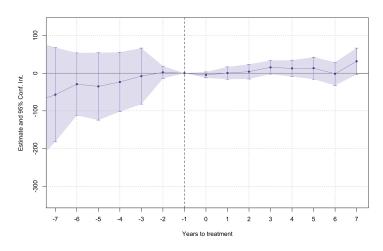
... and an increase in White residents



Property values increased in adjacent neighbourhoods

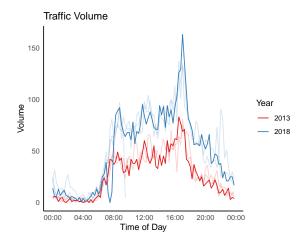


No impact on employment





Traffic increases on adjacent roads





Taking stock

After the removal of the Inner Loop, we observe

- 1. an increase in the total number of residents in nearby neighbourhoods, primarily White, higher-income residents
- 2. an increase in property values
- 3. no effect on employment
- 4. an increase in traffic volumes on substitute road

Model overview

Quantitative spatial model based on Allen and Arkolakis (2022) and Ahlfeldt et al. (2015) featuring

- 1. Workers differentiated by race and income who, conditional on locations on work work, choose
 - location of residence
 - which route to take when commuting to work
- 2. Endogenous traffic and congestion
- 3. Residential amenities which depend on
 - proximity to a highway (exogenous)
 - demographic composition (endogenous)
 - neighbourhood characteristics (observed and unobserved)

Workers

A worker m living in i and working in j and commuting via route r has utility

$$u_{mijr} = \frac{\xi_i B_{mi}}{\tau_{ijr}} \left(\frac{c_{mi}}{\alpha_m}\right)^{\alpha_m} \left(\frac{h_{mi}}{1 - \alpha_m}\right)^{1 - \alpha_m} \epsilon_{mir}$$

- ϵ_{mir} is drawn from a nested Fréchet distribution
- Two-step process:
 - 1. where to live
 - 2. which route to take

Choice probabilities

 The probability a worker m chooses to live in i, conditional on working in j

$$\pi_{mi|j} = \frac{\xi_i^{\theta} \left(\frac{B_{mi}}{q_i^{1-\alpha_m}}\right)^{\theta} \tau_{ij}^{-\theta}}{\sum_i \xi_{i'}^{\theta} \left(\frac{B_{mi'}}{q_{i'}^{1-\alpha_m}}\right)^{\theta} \tau_{i'j}^{-\theta}}$$

where τ_{ij} is the expected cost of commuting from i to j:

$$au_{ij} = \left(\sum_{r \in \mathcal{R}_{::}} au_{ijr}^{-
ho}
ight)^{-rac{1}{
ho}}$$

Preference heterogeneity

- Single residential amenity b_i with preference parameter β_m
- Utility from amenity b_i is $B_{mi} = b_i^{\beta_m}$

$$\beta_m = \beta_0 + \beta_d' D_m$$

where D_m is a vector of demographic characteristics

Choice probabilities

$$\pi_{\textit{mi}|j} = \frac{\left(\frac{b_{i}^{\varphi'_{d}D_{\textit{m}}}}{q_{i}^{\alpha'_{d}D_{\textit{m}}}} \times \delta_{i} \times \tau_{ij}^{-1}\right)^{\theta}}{\sum_{i} \left(\frac{b_{i}^{\varphi'_{d}D_{\textit{m}}}}{q_{i}^{\alpha'_{d}D_{\textit{m}}}} \times \delta_{i} \times \tau_{ij}^{-1}\right)^{\theta}}$$

where

$$\delta_i = \xi_i \left(\frac{b_i^{\varphi_0}}{q_i^{1-\alpha_0}} \right)$$

• Similar to logit model of demand but with a multiplicative "mean utility" δ_i rather than additive



Discussion

- Benefit of preference heterogeneity
 - IID preference shock and lack of heterogeneity => unrealistic substitution patterns and inaccurate welfare impacts
 Substitution patterns
 Comparison to logit
 - Important when evaluating the impacts of large infrastructure projects
- Additional benefits:
 - can easily extend model to include random coefficients
 Random coeffs.
 - can include additional observable neighbourhood characteristics to the utility specification
 - if no random coefficients, possible to identify parameters from one cross-section of data

Residential amenities

Exogenous highway proximity

$$\exp(f(dist_i))$$

where f is a non-parametric function of distance

Endogenous racial composition

Percent White
$$i_i^{\beta_m^{peers}}$$

Total residential amenities

$$B_{mi} = f(dist_i) \Big(Percent \ White_i^{eta_m^{peers}} \Big) \prod_{t=1}^{I} b_i^{eta^t}$$

▶ Nbhd. chars.

Routing

- ullet City represented by an adjacency matrix $\mathcal{N} \equiv [d_{kl}]_{N imes N}$
 - $-d_{kl}$ is the cost of travelling directly from location k to l
 - If no direct link exists, $d_{kl} = \infty$
- Commuting cost of travelling along a link

$$d_{kl} = \exp(\kappa t_{kl})$$

• Travel time as function of traffic & road chars.

$$t_{kl} = \bar{t}_{kl} imes \left(rac{\Xi_{kl}^{\lambda_1}}{I_{kl}^{\lambda_2}}
ight)$$

Travel costs

• Total cost of travelling from *i* to *j* along route *r*

$$\tau_{ijr} = \prod_{kl \in r} d_{kl}$$

Compute expected travel costs as elements of

$$\mathbf{C} \equiv (\mathbf{I} - \mathbf{D})^{-1}$$
 where $\mathbf{D} \equiv \left[d_{ij}^{-
ho}
ight]$

→ Details

Traffic

Link intensity

$$\pi_{ij}^{kl} \equiv \left(rac{ au_{ij}}{ au_{ik} d_{kl} au_{lj}}
ight)^{
ho}$$

• Equilibrium traffic along link (k, l) is

$$\Xi_{kl} = \sum_{ij} \pi_{ij}^{kl} L_{ij}$$

Equilibrium

- 1. Workers maximize utility subject to their budget constraint
- 2. Residential amenities are as described earlier
- 3. Expectations over peer composition generates choices that are consistent with realized peer composition
- 4. Demand for residential housing is equal to supply of housing
- 5. Traffic equilibrium holds
- 6. For each demographic type k, $\sum_i L_{ik}^R = \bar{L}_k$

▶ Summary of parameters

Estimation overview

Adapt micro-BLP to estimate a QSM

Estimation proceeds in two parts

- 1. Traffic and congestion parameters estimated outside the model
- 2. Preference parameters estimated using GMM and IV

Estimation of preferences

Estimate $\{eta_d, lpha_d\}$ via GMM

- 1. Given κ and ρ , compute expected commute costs τ Details
- 2. Given τ , $\{\beta_d, \alpha_d \kappa\}$, search for δ 's such that

$$\hat{s}_i = \int_j \int_{m|j} \pi_{mi|j} dF(\nu_m, D_m) dH(L_j)$$

3. Construct micro-moments Micro-moments

Recover $\{\alpha_0, \beta\}, f(\cdot)$ from IV regression

$$\ln \delta_i = \beta_0' \ln b_i + (1 - \alpha_0) \ln q_i + f(dist_i) + \ln \xi_i$$

Inversion & contraction mapping

Challenge: Solving for δ 's is computationally intensive

Solution: Contraction mapping

Define the function f as

$$f(\delta) = \ln(\delta) + \ln(s) - \ln(s(\delta))$$

Assume δ_i is positive and finite for all $i \in \mathcal{N}$ and $\theta \in [c_0, c_1]$ for some positive constants $0 < c_0 < 1 < c_1$. Then f is a contraction mapping.

→ Proof sketch

Instruments

- **Price**: nbhds with higher ξ_i likely have higher prices
 - Gandhi and Houde (2020) differentiation instruments

 Details

 Exclusion restriction

 Instruments
- **Demographics**: shares are endogenous and may be correlated with ξ_i
 - Shift-share instruments from Davis, Gregory and Hartley (2023) → Details
 - Shift: national probability that a type of household lives in a neighbourhood with certain topographic characteristics
 - Share: city-level population shares of each type in Rochester

Traffic parameters

ullet Congestion λ_1 and impact of road infrastructure λ_2

$$\ln speed_{kl} = \beta_0 + \lambda_1 \ln(\Xi_{kl}) + \lambda_2 \ln(I_{kl}) + \beta' X_{kl} + \epsilon_{kl}$$

• κ from gravity equation

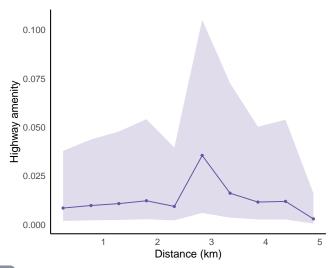
$$\ln L_{ij} = \gamma_i + \gamma_j + \kappa \ln t_{ij} + \eta_{ij}$$

Estimates

Parameter	Estimate	SE	Method	
λ_1	-0.0671	(0.0169)	OLS	→ Table
λ_2	0.0138	(0.0354)		
κ	-0.2438	(0.00173)	PPML	▶ Table
$lpha_{0}$	-0.2065	(0.1215)	IV	► Table
β_0^{peers}	-0.2613	(0.2689)		
α_h	0.186	(0.00159)	GMM	▶ Table
$\alpha_{\sf nw}$	-0.098	(0.00182)		
$eta_{\it nw}^{\it peers}$	-0.203	(0.00171)		

▶ Model fit

Highway amenity function

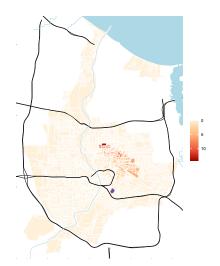




Changes in expected commuting costs

- \uparrow in τ in 5.3% of residence-workplace pairs
- \uparrow in τ to ≥ 1 workplace for 83% of all neighbourhoods
- † in expected commuting costs to 85% of workplaces for the most affected neighbourhood sees

Change in τ — an example







Change in unobserved amenities

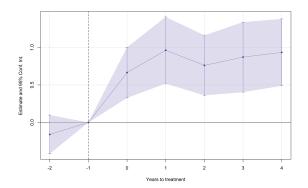
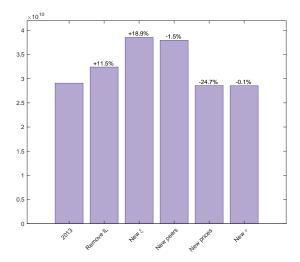
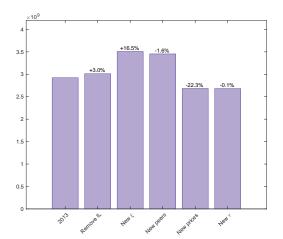


Figure 1: Difference-in-differences event study of model-implied unobserved amenity ξ

Change in aggregate welfare



Change in welfare — low-income, White





Introduction

Change in welfare — low-income, non-White

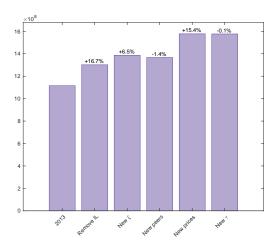


Figure 2: Change in welfare for low-income, non-White residents



Introduction

Conclusion

- Increase in the number residents living in nearby neighbourhoods
 - driven by higher-income, White residents
 - ↑ in property values of \$20,982 \implies ~9.4% increase
 - improvement in neighbourhood amenity
- Increase in expected commuting costs for 5.3% percent of residence-workplace pairs
 - ↑ in commuting costs to ≥ 1 workplace for 83% of nbhds
 - – ↑ expected commuting costs for 85% of workplaces in the most impacted nbhd.
- Modest decrease in aggregate welfare
 - – ↑ price offsets ↑ in amenities for White residents
 - gains overall for non-White residents

Takeaways

- Removing urban highways can be an effective tool for revitalizing declining cities
- Distributional effects depend on
 - initial local demographics
 - change in amenities
 - housing market responses
 - particular traffic conditions
- Reducing road infrastructure does not necessarily lead to large increases in commuting costs

Thank you!

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More background

- Over 1 million people and businesses were displaced during the construction of the highway system (USDOT)
- Nearly 30 cities across the US are discussing the removal of these highways
 - Removal completed: Rochester
 - Committed to removal: Detroit, Syracuse, New Haven & Somerville, Mass.,
 - Removal under study: Boston, Austin, Dallas, Seattle, New Orleans, and San Francisco, among others
- The Bipartisan Infrastructure Law (Nov. 2021) set aside \$1 billion towards "reconnecting communities that were previously cut off from economic opportunities by transportation infrastructure."
 - Reconnecting Communities Pilot Program (RCPP) grant program



History of the Inner Loop

- Constructed in the late 1950's/early 1960's
- Built for anticipated traffic volume that never materialized
 - In 1960s, population was \sim 332,000, declined to \sim 210,000 in 2010
- Since its completion, overall usage has declined as jobs and residents migrated away from the city

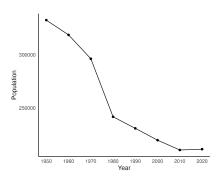


Figure 3: Rochester's population has declined steadily since 1950

▶ Decline in jobs

Inner Loop Background

- Initial discussions to eliminate the Inner Loop East and replace it with a boulevard began in the 1990s
- In 2013, the city received a \$17.7 million grant from the USDOT
- Removed highway segment was $\sim 2/3$ mile long (~ 1.07 km)
 - In some places had as many as twelve travel lanes and occupied a width ranging from 182 feet to 355 feet (curb to curb).
- The removal freed \sim 6 acres of land for new development
- Decision was largely motivated by traffic volumes, cost, and desire to reconnect neighbourhoods to downtown Rochester

■ Back

Decline in jobs

- In the 1980s, Eastman Kodak, Xerox Corporation & Bausch & Lomb, Inc. collectively employed over 50% of Rochester's labour force
 - 1973: Kodak employed > 60,000 workers
 - 2000: employed \sim 21,600 workers
 - 2012: filed for bankruptcy
 - 2013: employed 5129 workers
- Xerox relocated their headquarters from Rochester to Stamford, CT, in 1969
 - early 2000s: eliminated 1400 jobs
 - 2018: finished relocating all employees
- Bausch & Lomb, Inc.
 - mid-1980s: restructuring
 - 1999: sold off Ray-Ban to Luxottica Group
 - 2007: acquired by PE firm
 - 2013: relocated firm headquarters to New Jersey

City of Rochester's considerations

From Project Benefit Cost Analysis (2013)

- Cost savings from avoiding repairs
- Development of new land and increase in value of existing nearby parcels from improved aesthetics
- Re-establish connections between Downtown Rochester and residential neighbourhoods
 - Claimed that benefits would accrue to low-income residents
- Improved safety
- Improved health from increase in biking/walking and less pollution
- Jobs from construction
- Desire to retain/attract young workers



Decision to remove the southeast segment was driven by traffic and highway conditions

"The eastern portion was the **least traveled section in terms of vehicle volumes**; There were several bridges reaching end of life and in need of replacement and it was **cost-effective** (both near-and long-term) to simply fill in that portion rather than replace the bridges; TIGER money was awarded; and an overall desire to begin reconnecting neighborhoods that had been displaced through the original Inner Loop construction back to downtown Rochester."

— Genesee Transportation Council

√ Back

Related literature (I)

Transportation:

- Highways: Baum-Snow (2007, 2020), Duranton & Turner (2012), Brinkman & Lin (2022), Weiwu (2024), Valenzuela-Casasempere (2024), . . .
- Congestion: Duranton & Turner (2011), Kreindler (2023), Almagro et al. (2024), Bou Sleiman (2024), Mosquera (2024), ...

Residential sorting

- Schelling (1971), Bayer et al. (2007), Bayer et al. (2022),
 Davis et al. (2024), Almagro et al. (2022), ...
- → Quantify the impacts of removing a highway on nearby neighbourhoods, while allowing for sorting

Related Literature (II)

Quantitative spatial models:

- Epple and Sieg (1999), Ahlfeldt et al. (2015), Heblich et al. (2020), Allen and Arkolakis (2022), Tsivanidis (2023), Bordeu (2023), Severen (2023), Barwick et al. (2024), ...
- → Augment AA (2022) to include heterogeneous workers and endogenous amenities

Demand estimation:

- Berry (1994), Berry, Levinsohn & Pakes (1995), Petrin (2002),
 Berry, Levinsohn & Pakes (2004), Calder-Wang (2022), ...
- → Show how to apply demand estimation techniques from empirical IO to estimate preferences in QSMs

◆ Back

Matching of tax parcels

- Prior to 2014, a large fraction of tax parcel IDs are not unique $(\sim 75\%)$
- To create a panel, match using the following procedure
 - 1. If the tax parcel ID number is unique, match based on ID
 - If the ID number is not unique or no match is found, match based on address (street name, number, and if applicable, unit number)
 - 3. If addresses are not unique, match on address, owner name and property type
 - 4. If address, owner and property type are not unique (e.g. if an individual owns multiple units at the same address), match to the tax parcel with the closest property value.



Matching results

Year	Num. tax parcels	Num. non- unique IDs	Num. matched	Num. unmatched	Match rate (%)
1996	68279	51978	63024	5255	92.30
2000	67541	50663	63468	4073	93.97
2004	67191	50929	64233	2958	95.60
2008	66661	50464	64945	1716	97.43
2012	66254	50109	65582	672	98.99

Of unmatched properties

- vacant plots of land (62.88%)
- residential properties (17.64%),
- commercial properties (15.18%)
- community services (1.69%), public services (1.53%), recreation and entertainment (0.92%), industrial properties (0.15%)

Google Maps API

- Simulate travel times between the centroids of all bilateral pairs of Census blocks
- Departure time set to 8:30 am (peak AM rush hour)
- Date chosen at random; limited to weekdays
- Obtain 33,506 travel time observations

	Distance (km)	Travel time (minutes)
Median	5.22	9.53
Mean	6.77	10.20

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Neighbourhood amenities

Туре	Num. Observations
Total	1214
Area of Interest	43
Business/Industry	99
Cemetery	115
Golf Courses	43
Historic Places	189
Hospital	27
Industrial Parks	39
Shopping	149
Court	6
Cultural Building	29
DMV	10
Education	209
Government Building	24
Library	32
Museum	15
Playground	104
Post Office	42
Recreational Facility	2
Senior Center	11
Urgent Care	15
YMCA	11



Crime — number of incidents by year and type

Year	Aggravated Assault	Burglary	Larceny	Motor Vehicle Theft	Murder	Non- Negligent Manslaughte	Robbery	Negligent Manslaughter
2011	1036	3159	7575	729	29	4	743	0
2012	979	2715	7332	627	32	5	795	0
2013	864	2530	6737	532	41	0	882	0
2014	599	2127	5833	554	26	1	686	0
2015	627	1731	5530	566	31	0	624	0
2016	603	1448	5405	503	36	2	658	0
2017	623	1327	5716	487	27	1	708	0
2018	644	1180	4998	465	24	3	512	0
2019	691	1287	5088	550	35	0	465	1
2020	993	1459	4748	799	49	1	478	0
2021	937	953	4205	960	72	6	486	1
2022	794	1012	5499	1118	74	2	508	0
2023	906	1048	5402	3942	50	4	445	0
2024	894	942	4031	2095	38	3	426	1
2025	156	111	877	442	8	1	80	0

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School summary statistics

• 102 schools; 27 private, 71 public, 2 charter, 2 pre-K

Year	Avg. class size	Pct. <3 years exp.	Pct. teachers with masters +	Pct 3+ English (HS)	Pct. 3+ math (HS)	Pct. 3+ science (HS)	Pct. 3+ English (grade 4)
2013	20.694	3.006	12.110	0.694	0.723	0.707	0.268
2014	20.966	4.276	11.883	0.678	0.694	0.680	0.303
2015	20.716	4.233	11.785	0.683	0.700	0.679	0.299
2016	20.924	4.276	11.791	0.700	0.715	0.691	0.360
2017	20.339	7.859	6.595	0.697	0.704	0.686	0.335
Year	Avg.	Pct. 3+	Avg.	Pct. 3+	Avg.	Pct. 3+	Avg.
	English	English	math	math	math	math	math
	score (grade 4)	(grade 8)	score (grade 8)	(grade 4)	score (grade 4)	(grade 8)	score (grade 8)

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Map of East Ave.

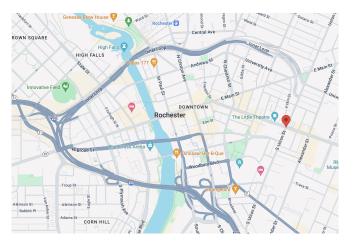


Figure 4: East Ave. and Union St.

Population and income

	Rochester	Treated	Control
Num. Census blocks	3,011	77	240
Avg. population	69.7	95.5	38.4
Avg. White share	0.39	0.72	0.22
Avg. Black share	0.38	0.13	0.56
Avg. Hispanic share	0.16	0.07	0.18
Avg. median HH income	30,541	32,958	18,283
Avg. median HH income (White)	37,403	35,730	15,528
Avg. median HH income (Black)	24,819	16,778	17,328
Avg. median HH income (Hispanic)	24,744	10,064	13,058

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Workers by residence and workplace

	Rochester	Treated	Control
By residence:			
Avg. num. workers	31	53	16
Avg. share <30 years	.31	0.44	0.36
Avg. share 30-54 years	0.53	0.47	0.52
Avg. share >54 years	0.15	0.09	0.13
Avg. share earning <\$1250/month	0.33	0.31	0.39
Avg. share earning \$1250 to \$3333/month	0.44	0.41	0.44
Avg. share earning >\$3333/month	0.23	0.28	0.17
Avg. share white-collar industries	0.33	0.34	0.35
Avg. share White	0.59	0.79	0.41
Avg. share college grad.	0.15	0.14	0.12
By workplace			
Avg. num. workers	57	102	78
Avg. share <30 years	0.24	0.31	0.19
Avg. share 30-54 years	0.56	0.51	0.56
Avg. share >54 years	0.20	0.18	0.25
Avg. share earning <\$1250/month	0.39	0.45	0.34
Avg. share earning 1250to3333/month	0.39	0.34	0.40
Avg. share earning >\$3333/month	0.22	0.21	0.26
Avg. share white-collar industries	0.28	0.36	0.31
Avg. share White	0.79	0.82	0.69
Avg. share college grad.	0.17	0.21	0.18

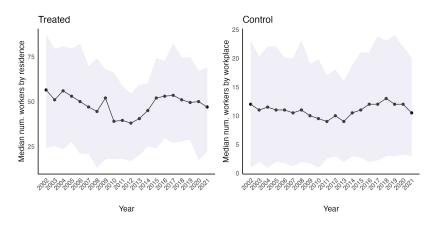


Property value

	Rochester	Treated	Control
Num. properties	66,254	1,572	2,878
Residential share	0.80	0.55	0.55
Commercial share	0.11	0.40	0.22
Vacant share	0.08	0.03	0.17
Avg. property value (\$)	111,466	222,882	125,813
Avg. property value per sqft (\$)	44	52	38
Share vacant land	0.08	0.01	0.09

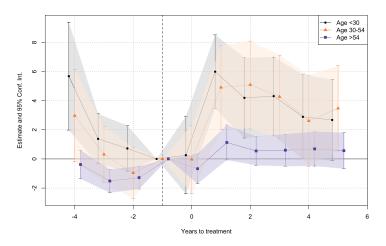
◆ Back

Levels over time in treated and control neighbourhoods



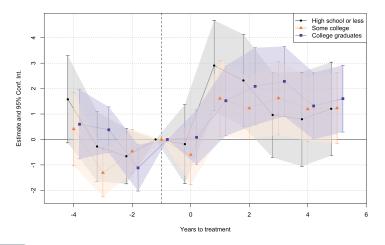
∢ Back

Larger increase in younger workers



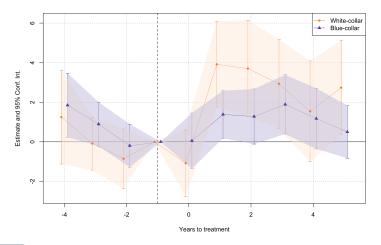


No substantial difference by education





... or by industry





No systematic changes in the spatial distribution of work

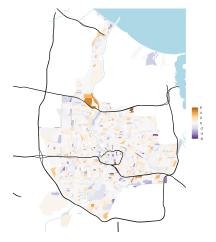
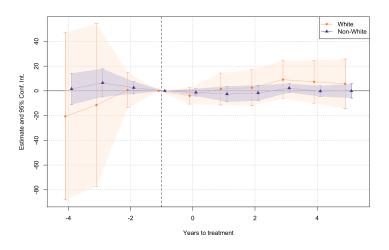


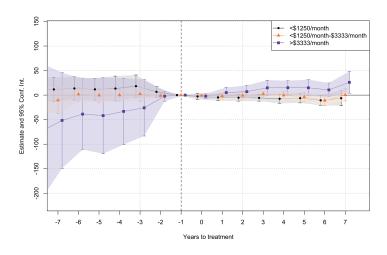
Figure 5: Percent change in number of workers between 2010 and 2019



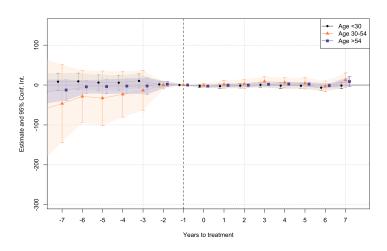
Workers by race



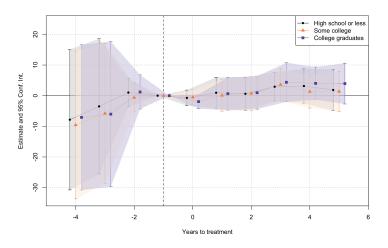
Workers by income



Workers by age

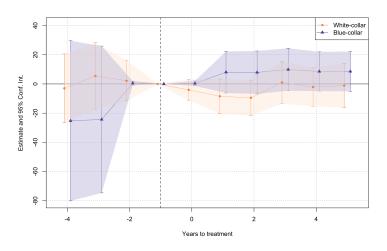


Workers by education





Workers by industry



Summary of model parameters

Parameter	Description
θ	Fréchet shape parameter on residences
ho	Fréchet shape parameter on routes
κ	Semi-elasticity of commuting costs
	with respect to travel times
$\alpha_0, \alpha_{nw}, \alpha_I$	Price elascitity
$f(\cdot)$	Highway disamenity function
$\beta_0^{p\acute{e}ers}, \beta_{nw}^{peers}$	Demographic preferences
$\{\beta^1,\ldots,\beta^T\}$	Preferences for observed neighbourhood characteristics
λ_1	Congestion (elasticity of travel time with respect to traffic)
λ_2	Elasticity of travel time with respect to road infrastructure

Substitution patterns

Elasticity of s_i with respect to characteristic k in location l

Without any heterogeneity

$$\varepsilon_{ilk} = \begin{cases} \beta_k \theta (1 - \pi_i) & \text{if } i = l \\ -\beta_k \theta \pi_l & \text{if } i \neq l \end{cases}$$

With heterogeneity

$$\varepsilon_{ilk} = \begin{cases} \frac{\theta}{s_i} \int_j \int_{m|j} \beta_k \pi_{mi} (1 - \pi_{mi}) dF_j(\nu, D) dH(L_j) & \text{if } i = I \\ -\frac{\theta}{s_i} \int_j \int_{m|j} \beta_k \pi_{mi} \pi_{ml} dF_j(\nu, D) dH(L_j) & \text{if } i \neq I \end{cases}$$

4 Back

Comparison to logit

Elasticity of shares in location i, s_i , with respect to characteristic k in location l

Multiplicative utility, Fréchet shocks

$$\varepsilon_{ilk} = \begin{cases} \beta_k \theta (1 - \pi_i) & \text{if } i = l \\ -\beta_k \theta \pi_l & \text{if } i \neq l \end{cases}$$

Linear utility, logit shocks

$$\varepsilon_{ilk} = \begin{cases} \beta_k b_k (1 - \pi_i) & \text{if } i = l \\ -\beta_k b_k \pi_l & \text{if } i \neq l \end{cases}$$

• cross-characteristic elasticity proportional to shares π_I and the same for all locations $i \neq I$

∢ Back

Random coefficients

- Assume there is a single residential amenity b_i with corresponding preference parameter β_m
- Utility from amenity b_i is $B_{mi} = b_i^{\beta_m}$
- Parametrize preference parameters α_m and β_m as

$$\beta_m = \beta_0 + \beta'_d D_m + \beta_\nu \nu_m^b$$

$$\alpha_m = \alpha_0 + \alpha'_d D_m + \alpha_\nu \nu_m^q$$

where $\nu_m^b \sim \mathcal{N}(0,1)$

Choice probabilities with random coefficients

$$\pi_{mi|j} = \frac{\left(\frac{b_i^{\varphi_d'D_m + \varphi_\nu \nu_m^b}}{\alpha_i^{\varphi_d'D_m + \alpha_\nu \nu_m^q}} \times \delta_i \times \tau_{ij}^{-1}\right)^{\theta}}{\sum_i \left(\frac{b_i^{\varphi_d'D_m + \varphi_\nu \nu_m^b}}{\alpha_i^{\varphi_d'D_m + \alpha_\nu \nu_m^q}} \times \delta_i \times \tau_{ij}^{-1}\right)^{\theta}}$$

where

$$\delta_i = \xi_i \left(\frac{b_i^{\varphi_0}}{q_i^{1-\alpha_0}} \right)$$

• Similar to mixed logit but with a multiplicative "mean utility" δ_i rather than additive



Choice probabilities with work location choice

$$\pi_{\textit{mij}} = \frac{\left(\frac{b_{i}^{\varphi'_{d}D_{m} + \varphi_{\nu}\nu_{m}^{b}}}{q_{i}^{\alpha'_{d}D_{m} + \alpha_{\nu}\nu_{m}^{d}}} \times \delta_{ij} \times \tau_{ij}^{-1}\right)^{\theta}}{\sum_{i} \left(\frac{b_{i}^{\varphi'_{d}D_{m} + \varphi_{\nu}\nu_{m}^{b}}}{q_{i}^{\alpha'_{d}D_{m} + \alpha_{\nu}\nu_{m}^{d}}} \times \delta_{ij} \times \tau_{ij}^{-1}\right)^{\theta}}$$

where

$$\delta_{ij} = \xi_{ij} \left(w_j \frac{b_i^{\varphi_0}}{q_i^{1-\alpha_0}} \right)$$

- Inversion recovers δ_{ij}^{θ}
- Identify θ from labour supply (requires a labour demand shifter)

Observable neighbourhood characteristics

- Share of land that is residential
- Computed distance to closest
 - office building
 - cemetery
 - hospital
 - historical landmark
 - library
 - museum
 - "area of interest" (e.g. theater, community center, sports park, art gallery etc.)
 - cultural building (e.g. historical society, cultural center, planetarium, etc.)
 - recreational facility
 - government building
 - playground
 - senior center

School characteristics

- Percent deemed proficient in grade 8 math and high school Regents Exam math
- Needs index
- Computed from average of three nearest public elementary/middle schools and three nearest public high schools

Crime

- Number of incidents per neighbourhood
- Number of burglaries per neighbourhood
- Share of incidents involving a firearm

Expected travel costs

Can express expected travel costs as

$$\tau_{ij}=c_{ij}^{-\frac{1}{\rho}}$$

where c_{ij} is the i, j-th element of matrix

$$\mathbf{C} \equiv (\mathbf{I} - \mathbf{D})^{-1}$$
 where $\mathbf{D} \equiv \left[d_{ij}^{-
ho}
ight]$

 D is the adjacency matrix of the network (city), weighted by scaled commuting costs

◆ Back

Expected travel cost details I

Expected travel costs are defined as

$$\tau_{ij} = \left(\sum_{r \in \mathcal{R}_{ij}} \tau_{ijr}^{-\rho}\right)^{-\frac{1}{\rho}}$$

Can rewrite in matrix form as

$$\left[\tau_{ij}^{-\rho}\right] = \sum_{K=0}^{\infty} \mathbf{D}^{K}$$

where

$$\mathbf{D} \equiv \begin{pmatrix} d_{11}^{-\rho} \cdots d_{1N}^{-\rho} \\ \vdots \ddots \vdots \\ d_{N1}^{-\rho} \cdots d_{NN}^{-\rho} \end{pmatrix}$$

Expected travel cost details II

• If the spectral radius (maximum absolute eigenvalue) of **D** is less than one, this geometric sum can be expressed as

$$\sum_{K=0}^{\infty} \mathbf{D}^K = (\mathbf{I} - \mathbf{D})^{-1} \equiv \mathbf{C}$$

where

$$\left[au_{ij}^{-
ho}
ight]={f C}$$

∢ Back

Micro-moments

1. Shares of nbhd choices by type (race, skill):

$$\hat{s}_{i|D} = \int_{j} \int_{m|j} \pi_{mi|j} dF(\nu_{m}) dH(L_{j})$$

2. Shares of location choices conditional on j and s:

$$\hat{s}_{i|j,s} = \int_{m|j} \pi_{mi|j} dF(\nu_m, g_m)$$

3. Within each nbhd i, shares of each demographic type:

$$\hat{s}_{D|i} = \frac{s_{i|D}\hat{s}_D}{s_i}$$

4. Conditional on nbhd i, share of residents working in j:

$$\hat{s}_{j|i} = \frac{s_{i|j}\hat{s}_j}{s_i}$$

Choice probabilities

$$\pi_{mi|j} = \frac{\xi_{i}^{\theta} \left(\frac{b_{i}^{\varphi_{0}+\varphi'_{d}D_{m}+\varphi_{\nu}\nu_{m}^{b}}}{q_{i}^{1-\alpha_{0}+\alpha'_{d}D_{m}+\alpha_{\nu}\nu_{m}^{q}}}\right)^{\theta} \tau_{ij}^{-\theta}}{\sum_{i} \xi_{i}^{\theta} \left(\frac{B_{mi}}{q_{i}^{1-\alpha_{m}}}\right)^{\theta} \tau_{ij}^{-\theta}}$$

$$= \frac{\left(\frac{b_{i}^{\varphi'_{d}D_{m}+\varphi_{\nu}\nu_{m}^{b}}}{q_{i}^{\alpha'_{d}D_{m}+\alpha_{\nu}\nu_{m}^{q}}}\right)^{\theta} \xi_{i}^{\theta} \left(\frac{b_{i}^{\varphi_{0}}}{q_{i}^{1-\alpha_{0}}}\right)^{\theta} \tau_{ij}^{-\theta}}{\sum_{i} \xi_{i}^{\theta} \left(\frac{B_{mi}}{q_{i}^{1-\alpha_{m}}}\right)^{\theta} \tau_{ij}^{-\theta}}$$

∢ Back

Commuting costs

Expected travel costs are defined as

$$\tau_{ij} = \left(\sum_{r \in \mathcal{R}_{ij}} \tau_{ijr}^{-\rho}\right)^{-\frac{1}{\rho}}$$

$$= \left(\sum_{r \in \mathcal{R}_{ij}} \left(\prod_{kl \in r} \exp(\kappa t_{kl})\right)^{-\rho}\right)^{-\frac{1}{\rho}}$$

◆ Back

Contraction mapping (I)

Proposition (BLP, 1995): Consider the metric space ($\mathbb{R}^{\mathbb{N}}$, d) with d(x,y) = ||x-y||. Let $f: \mathbb{R}^{\mathbb{N}} \to \mathbb{R}^{\mathbb{N}}$ have the following characteristics:

1. For all $x \in \mathbb{R}^{\mathbb{N}}$, f(x) is continuously differentiable, with, for all i and k,

$$\frac{\partial f_i(x)}{\partial x_k} \ge 0$$

and

$$\sum_{k=1}^{N} \frac{\partial f_i(x)}{\partial x_k} < 1$$

- 2. $\min_i \inf_k f_i(x) \equiv x > -\infty$
- 3. There is a value, \bar{x} , with the property that if, for any i, $x_i \geq \bar{x}$, then for some k (not necessarily equal to i), $f_k(x) < x_k$.

Then, there is a unique fixed point, x_0 , to f in $\mathbf{R}^{\mathbf{N}}$. Further, let the set $X = [x, \bar{x}]^N$, and define the truncated function $\hat{f}: X \to X$ as $\hat{f}(x) = \min\{f_j(x), x\}$. Then $\hat{f}(x)$ is a contraction of modulus less than one on X.

Contraction mapping (II)

Assumption 1:

- $f(\delta)$ is continuously differentiable since $\log(\delta)$ and $s(\delta)$ are continuously differentiable.
- $\frac{\partial f_i(x)}{\partial x_k} \ge 0$ if

$$heta \leq c_1 \equiv \min_i rac{s_i}{\int_j \int \pi_{mi} (1 - \pi_{mi}) dF(\nu_m, D_m) dH(L_j)}$$

• $\sum_{k=1}^{N} \frac{\partial f_i(x)}{\partial x_k} < 1$ if

$$c_0 \equiv \frac{1/\delta_i}{\sum_{k=1}^N 1/\delta_k} < \theta$$

■ Back

Contraction mapping (III)

Assumption 2: Requires $f(\delta)$ to be bounded below

Define

$$D_i(\delta) \equiv \frac{s_i(\delta)}{\delta_i}$$

and rewrite (δ) as

$$f(\delta) = \ln(s_j) - \ln(D_j(\delta))$$

- Since $c_2 \le \delta \le c_3$, $D_i(\delta)$ is bounded above.
- Let $d = \max_{\delta} D_i(\delta)$.
- Then $f_i(\delta)$ is bounded below by $d = \ln(s_i) \ln(d)$

◆ Back

Contraction mapping (IV)

Assumption 3:

- Lemma: There is a value $\bar{\delta}$ such that if an element of δ , e.g. δ_j , is greater than $\bar{\delta}$, then there is an neighbourhood k such that $s_k(\delta) > s_k$.
- For such k,

$$f_k(\delta) = \ln(\delta_k) + \underbrace{\ln(s_k) - \ln(s_k(\delta))}_{<0} < \ln(\delta_k) < \delta_k$$

4 Back

Price instruments

- Measures of distance between neighbourhood i and other neighbourhoods in characteristics space
- Use exogenous characteristics of housing in neighbourhoods in a 5-10 km ring around the focal neighbourhood to address potential spatial correlation

$$z_{i}(\mathbf{x}) = \begin{cases} \sum_{i' \neq i} d_{i,i'}^{k} & \forall k \\ \sum_{i' \neq i} d_{i,i'}^{k} \times d_{i,i'}^{l} & \forall k \neq l \\ \sum_{i' \neq i} \mathbf{1}(|d_{i,i'}^{k}| < \mathcal{T}_{k}) & \forall k \\ \sum_{i' \neq i} \mathbf{1}(|d_{i,i'}^{k}| < \mathcal{T}_{k}) \times d_{i,i'}^{l} & \forall k \neq l \end{cases}$$

where

- $d_{i,i'}^k = x_{i'}^k x_i^k$ measures the difference between neighbourhood i and i' along characteristic k
- \mathcal{T}_k is a proximity threshold

Exclusion restriction

Identifying assumption: characteristics of other neighbourhoods affect equilibrium prices but are uncorrelated with the unobserved amenity of the focal neighbourhood

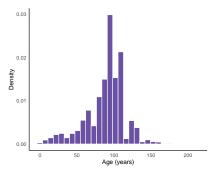


Figure 6: Density of age of residential housing

List of instruments

- Average difference in
 - Number of stories
 - Lot size (acres)
 - Square footage
 - Number of rooms, bedrooms & bathrooms
 - Age of residential housing
 - Lot frontage
- Interactions in differences
 - Square footage x Number of rooms
 - Square footage x Lot size
 - Number of stories x
 Number of rooms
 - Lot size x Age of residential housing

- Number of neighbourhoods such that the difference in characteristic $k < \mathcal{T}_k$
 - Number of stories
 - Lot frontage
 - Age of residential housing
- Difference in characteristic k
 x number of neighbourhoods
 such that the difference in
 k < T_k
 - Lot depth
 - Lot frontage
 - Age of residential housing



Peer instrument details

White share in a given neighbourhood *i*:

$$S_i^{w} = \frac{\sum_{k} \mathbf{1}(k \in White) s^k \rho_i^k}{\sum_{k'} s^{k'} \rho_i^{k'}}$$

Predicted white share in neighbourhood *i*:

$$z_i^w = \frac{\sum_k \mathbf{1}(k \in White) s^k \hat{\rho}_{q(i)}^k}{\sum_{k'} s^{k'} \hat{\rho}_{q(i)}^{k'}}$$

where

- s^k is the share of household type k in Rochester
- ρ_i^k is the probability that a type k household lives in neighbourhood i
- $\hat{\rho}_{q(i)}^{k}$ is the estimated probability that a type k household lives in a neighbourhood in income quantile q(i)

Congestion and infrastructure elasticity

	log(speed)			
	(1)	(2)		
log(traffic flow)	-0.0824***	-0.0671***		
	(0.0071)	(0.0169)		
log(infrastructure)		0.0138		
		(0.0354)		
Observations	261,690	164,674		
Adjusted R ²	0.74682	0.39008		
Dand sammant FF				
Road segment FE Direction FE	V	_		
Year FE	v	•		
Month FE	V	•		
	V	V		
Day of week FE	✓	v		
Road type FE		✓_		
Speed limit FE		✓		
Pavement type FE		✓		
Divided highway FE		✓		
One way FE		✓		
Parkway FE		✓		

Notes: *p<0.1; **p<0.05; ***p<0.01



Commuting elasticity κ

	(1)	(2)	(3)
	High-income	Low-income	Pooled
		In(flows)	
In(travel time)	-0.1042**	-0.3207***	-0.2438***
	(0.00956)	(0.00394)	(0.00173)
Residence FE	Yes	Yes	Yes
Workplace FE	Yes	Yes	Yes
Observations	24,425	24,425	24,425

Notes: Travel times t_{ij} between locations i and j are simulated via the Google Maps API with departure times of 8:30 am to reflect peak rush hour traffic conditions on a weekday. *p<0.1; **p<0.05; ***p<0.01



Preference parameters (I)

	OLS	IV-BI	IV-BLP		IV-GH	
	(1)	(2)	(3)	(4)	(5)	
log(house price index)	0.1578***	-0.1268	-0.0483	-0.2501**	-0.2065*	
log(white share)	(0.0234) -0.1935*** (0.0348)	(0.1528) -0.1629*** (0.0396)	(0.1702) -0.1471 (0.3512)	(0.1168) -0.1443*** (0.0429)	(0.1215) -0.2613 (0.2689)	
Highway distance function	✓	✓	✓	√	√	
Land use	✓	✓	✓	✓	✓	
Nbhd. amenities	✓	✓	✓	✓	✓	
Education outcomes	✓	✓	✓	✓	✓	
Poverty	✓	✓	✓	✓	✓	
Crime	✓	✓	✓	✓	✓	
Observations	11,450	11,450	11,450	9,665	9,665	
F-test (1st stage), log(house price index)		81.002	92.428	43.214	46.575	
F-test (1st stage), log(white share)			119.10		27.054	

Notes: IV-BLP in columns (2) and (3) use Berry (1995) instruments for price. IV-GH in columns (4) and (5) uses Gandhi and Houde (2019) differentiation instruments for price. Instruments for peers are shift-share instruments proposed by Davis et al. (2024). Standard errors are clustered at the Census tract level. $^*p<0.1; ^{**}p<0.05; ^{***}p<0.01$

■ Back

▶ Controls

Controls

- Land use: share of land
 - single-family homes
 - residential housing
 - commercial properties
 - community services (e.g. schools, libraries, religious buildings)
- Nbhd, amenities: distance to
 - Genesee River
 - Lake Ontario
 - nearest office building complex, cemetery, hospital, historical landmark, library, cultural building, courthouse, DMV, government building, recreational facility, playground, and senior center

- Education outcomes: percent of students proficient in math on the HS Regent's Exam and the eighth grade NYS standardized math test at the three nearest schools
- Proxy for poverty: Needs Index (NYSED)
- Crime:
 - number of incidents
 - the share of incidents involving a firearm
 - the number of burglaries
 - number of incidents × share involving a firearm
 - number of burglaries × share involving a firearm



Preference parameters (II)

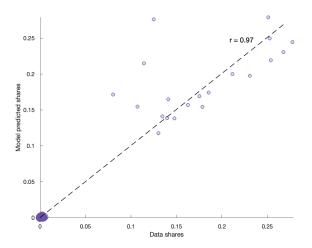
Parameter	Estimate
α_h	0.186***
	(0.00159)
$\alpha_{\sf nw}$	-0.098***
	(0.00182)
$eta_{\sf nw}^{\sf peers}$	-0.203***
	(0.00171)
	**

Notes: *p<0.1; **p<0.05; ***p<0.01

- High-income residents are less price sensitive
- Minority residents are more price sensitive
- Minority residents exhibit a distaste for neighbourhoods with larger shares of White residents



Model fit

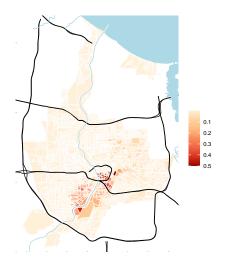




Preferences for highway proximity

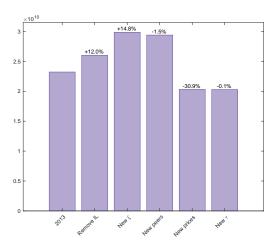
	OLS	IV-	IV-BLP		IV-GH	
	(1)	(2)	(3)	(4)	(5)	
f(dist. to hw) bin 1	-7.091***	-5.263***	-5.781***	-4.549***	-4.765***	
· ·	(0.2915)	(1.013)	(0.9869)	(0.8078)	(0.7605)	
f(dist. to hw) bin 2	-6.877** [*]	-5.074* <i>*</i> *	-5.582** [*]	-4.395** [*]	-à.623** [*]	
,	(0.2865)	(1.000)	(1.006)	(0.7905)	(0.7614)	
f(dist. to hw) bin 3	-6.713** [*]	-4.963***	-5.453***	-à.296** [*]	-4.529** [*]	
,	(0.2889)	(0.9717)	(0.9987)	(0.7739)	(0.7589)	
f(dist. to hw) bin 4	-6.552** [*]	-à.816** [*]	-ŝ.302** [*]	-4.167** [*]	-à.401** [*]	
(, , .	(0.2963)	(0.9631)	(1.001)	(0.7664)	(0.7570)	
f(dist. to hw) bin 5	-6.655** [*]	-s̀.033** [*]	-5.485***	-à.443** [*]	-4.671** [*]	
(,	(0.3067)	(0.9092)	(0.9682)	(0.7315)	(0.7348)	
f(dist. to hw) bin 6	-Š.981** [*] *	-À.111** [*]	-à.631** [*]	-3.055** [*]	-3.337** [*]	
,	(0.4162)	(1.090)	(1.127)	(0.8952)	(0.9067)	
f(dist. to hw) bin 7	-6.421** [*]	-4.702***	-5.180***	-3.880***	-4.127***	
,	(0.3223)	(0.9653)	(1.019)	(0.7629)	(0.7668)	
f(dist. to hw) bin 8	-6.629***	-4.981***	-5.439***	-4.218***	-4.458***	
,	(0.3174)	(0.9185)	(0.9907)	(0.7388)	(0.7481)	
f(dist. to hw) bin 9	-6.642***	-4.955***	-5.425***	-4.190***	-4.428***	
((0.3414)	(0.9701)	(1.015)	(0.7621)	(0.7681)	
f(dist. to hw) bin 10	-8.453***	-6.488***	-7.037* [*] *	-5.549** [*]	-5.816***	
, , , ,	(0.3597)	(1.083)	(1.129)	(0.8674)	(0.8599)	
Observations	11,450	11,450	11,450	9,665	9,665	
F-test (1st stage), log(house price index)	,	81.002	92,428	43.214	46.575	
F-test (1st stage), log(white share)			119.10		27.054	

Average change in au





Change in welfare — high-income, White



Change in welfare — high-income, non-White

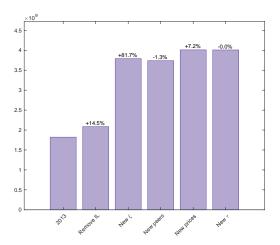


Figure 7: Change in welfare for high-income, non-White residents