OLD DOMINION UNIVERSITY

The causal effect of citywide speed limit reduction on crash risk

Presented by Dr. Kun Xie

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Agenda

- Introduction
  - Background
  - Challenges and solutions
- Data Preparation
- Method
  - PSM (Propensity Score Matching)
  - SDID (Spatial Difference in Differences)
- Results
- Conclusions

Introduction: Background

- Citywide speed limit reduction in New York City
  - The default speed limit was changed from 30 mph to 25 mph.
  - Effective on November 7th, 2014.
- Safety impacts
  - Give road users more time to react to unexpected safety-related events.
  - Reduce impact speeds when crashes occur.

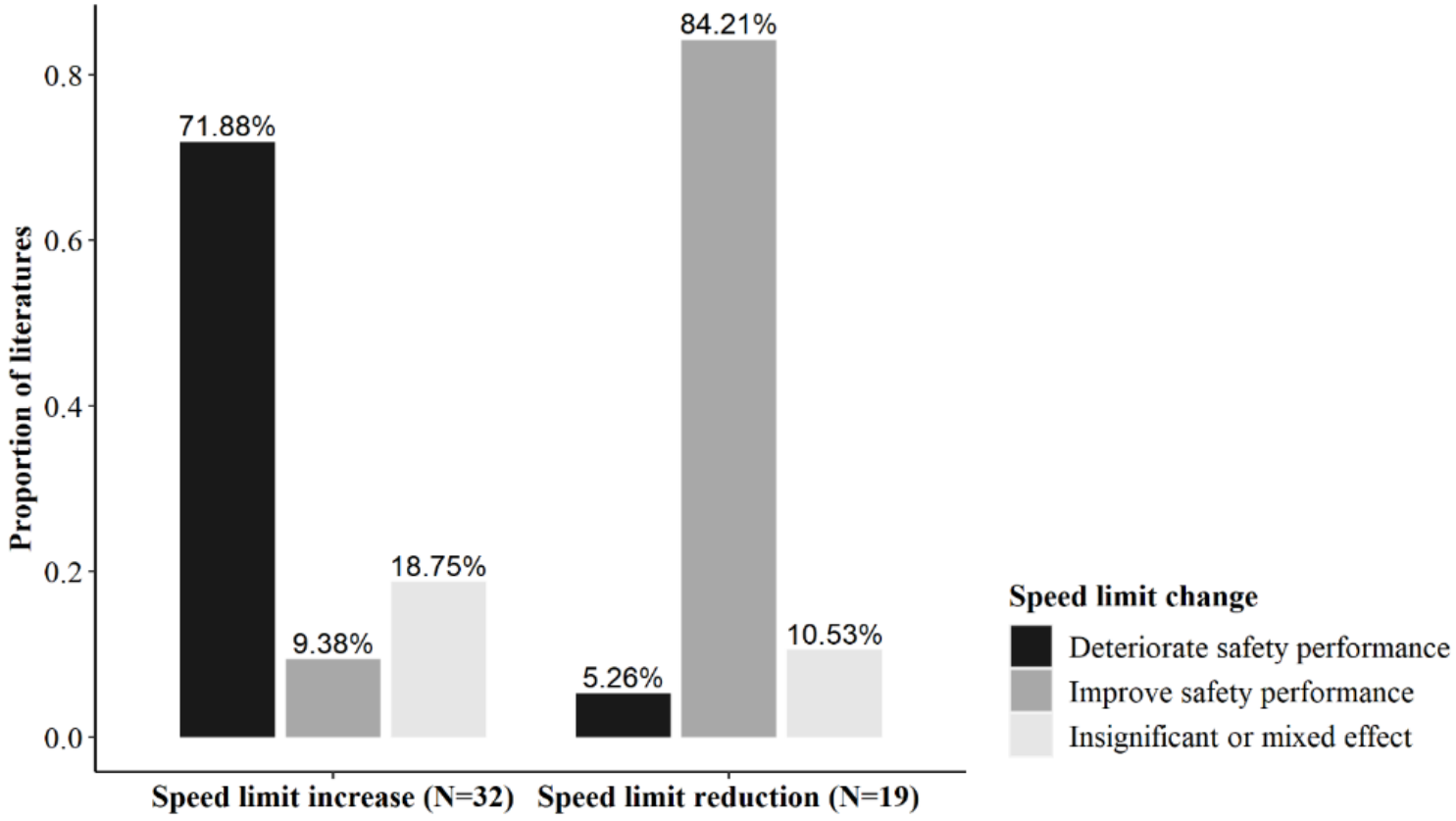
Source: https://www1.nyc.gov/html/dot/html/motorist/vision-zero-safe-driving.shtml

Introduction: Background

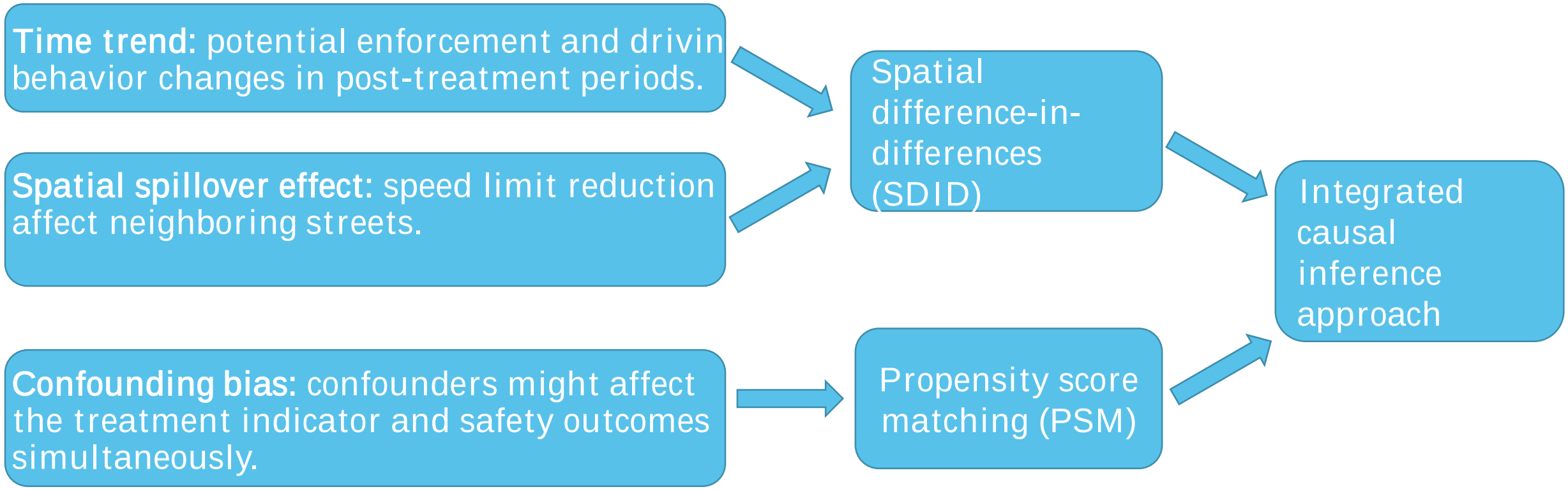
- Randomized control trails (RCTs) are the “Gold Standard”
- Drawbacks of RCTs?:
  - Cost
  - Unethical
- What can we do when an experiment is not possible?
  - Observational studies

Introduction: Background

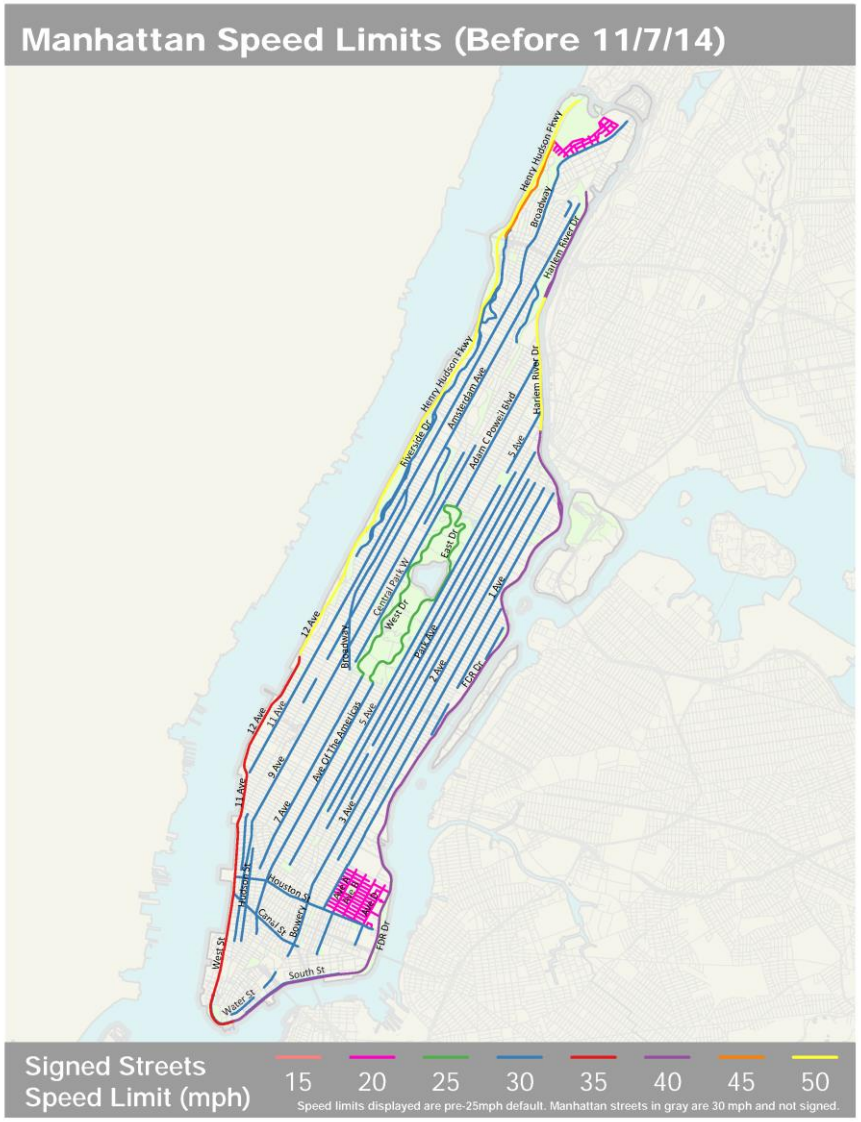
- Previous observational studies on safety effectiveness of speed limit changes (before 2021)

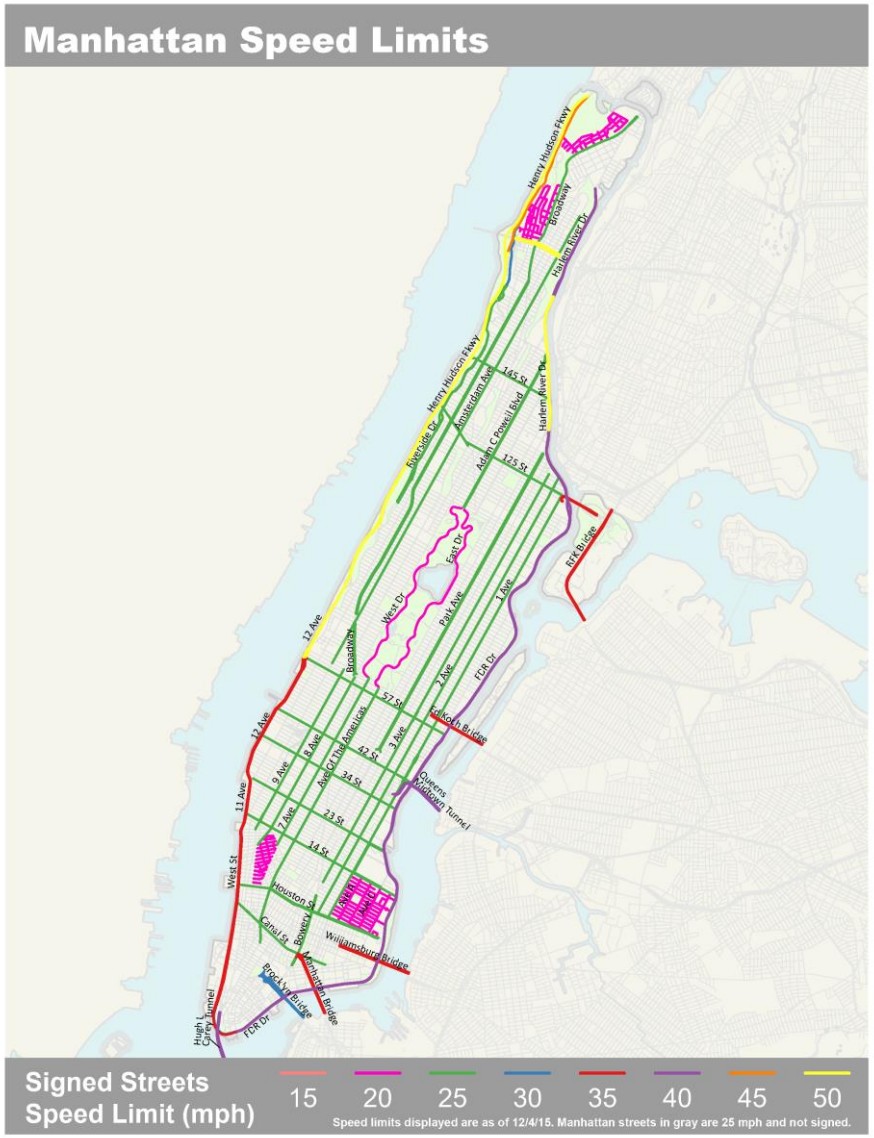


Introduction: Challenges and Solutions



Data Preparation: Speed Limit Reduction



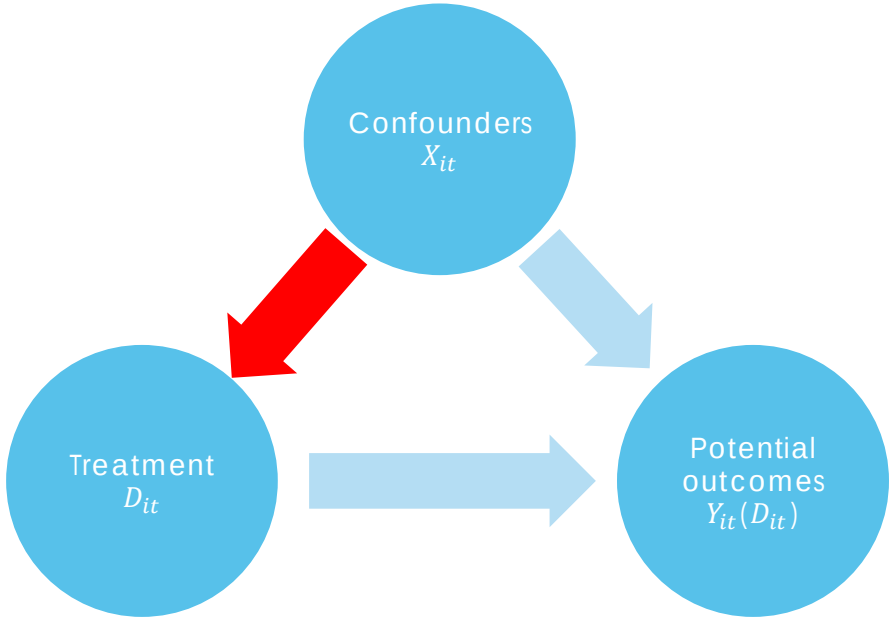


Source: https://www1.nyc.gov/html/dot/downloads/pdf/current-pre-vision-zero-speed-limit-maps.pdf

Variables	Before the speed limit reduction (year: 2013)				After the speed limit reduction (year: 2015)			
	Treatment sites		Control sites		Treatment sites		Control sites	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Fatal crash frequency	0.07	0.30	0.04	0.25	0.06	0.27	0.06	0.33
Injury crash frequency	11.04	17.97	7.17	12.20	9.99	16.02	6.17	11
PDO crash frequency	43.38	80.67	29.65	49.71	46.32	84.37	30.10	54.04
Bronx (no = 0, yes = 1)	0.18	0.38	0.06	0.25	0.18	0.38	0.06	0.25
Brooklyn (no = 0, yes = 1)	0.27	0.45	0.13	0.33	0.27	0.45	0.13	0.33
Manhattan (no = 0, yes = 1)	0.19	0.39	0.22	0.41	0.19	0.39	0.22	0.41
Queens (no = 0, yes = 1)	0.29	0.45	0.34	0.48	0.29	0.45	0.34	0.48
Staten Island (no = 0, yes = 1)	0.07	0.25	0.24	0.43	0.07	0.25	0.24	0.43
Arterial street (no = 0, yes = 1)	0.37	0.48	0.48	0.50	0.37	0.48	0.48	0.50
One-way street (no = 0, yes = 1)	0.51	0.50	0.66	0.48	0.51	0.50	0.66	0.48
Number of intersections	10.60	13.44	8.04	10.89	10.60	13.44	8.04	10.89
Log VMT (vehicle. mile)	7.72	1.48	8.27	1.62	7.67	1.52	8.27	1.62
Number of lanes	2.31	1.13	3.19	1.96	2.31	1.17	3.21	1.97
Number of	3,745		467		3,745		467	

Methods

- Ignorability assumption: $(Y_{it}(0), Y_{it}(1)) \perp D_{it} \,|\, X_{it}$
- Positivity assumption: $0 < P(D_{it} \mid X_{it}) < 1$
- SUTVA (Stable unit treatment value assumption): Potential outcomes of one site are unrelated to treatment status of other sites



Methods: PSM

- Logistic generalized additive model: identify nonlinear relationships between the treatment indicator and covariates.

- The propensity score $e_i(\mathbf{X}_{i0})$

$$E(\log(\frac{e_i(\mathbf{X}_{i0})}{1-e_i(\mathbf{X}_{i0})})) = \beta_0 + \beta_1 X_{1,i0} + \beta_2 X_{2,i0} + \ldots + \beta_{p-1} X_{p-1,i0} + f_p(X_{p,i0})$$

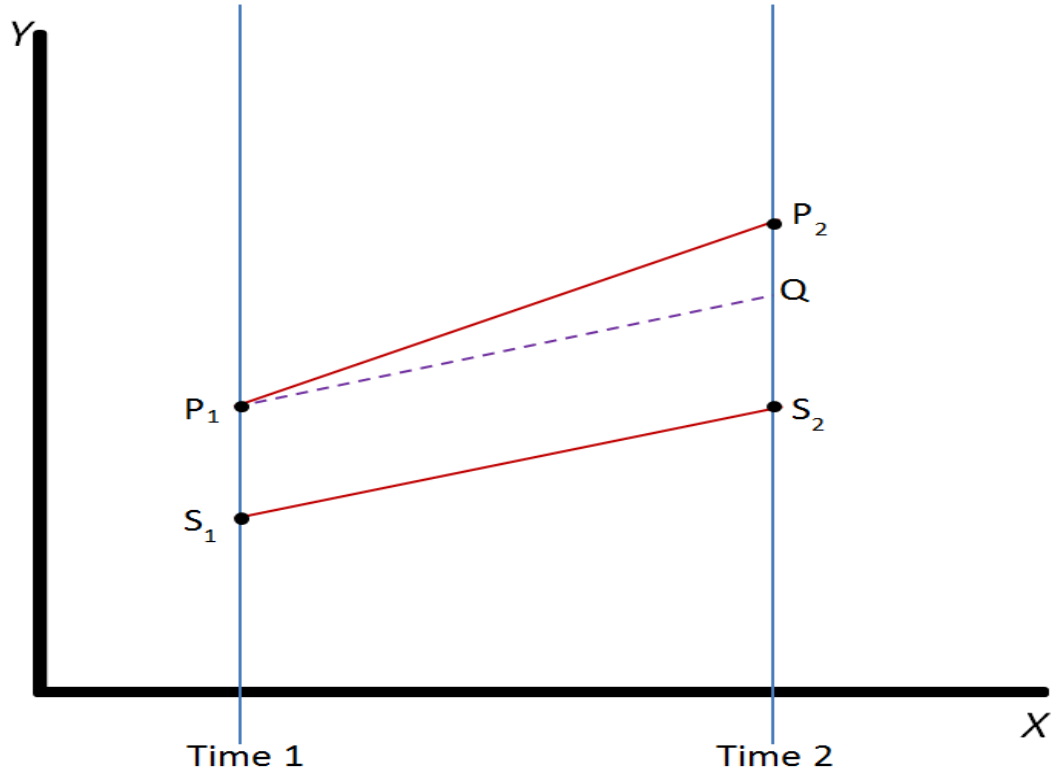
Smooth function between the p_{th} X_{i0} and D_{i0} at site i

Pre-treatment covariates at site i

- Matching with replacement: repeated use of control sites (much more treatment sites than control sites).

Methods: SDID

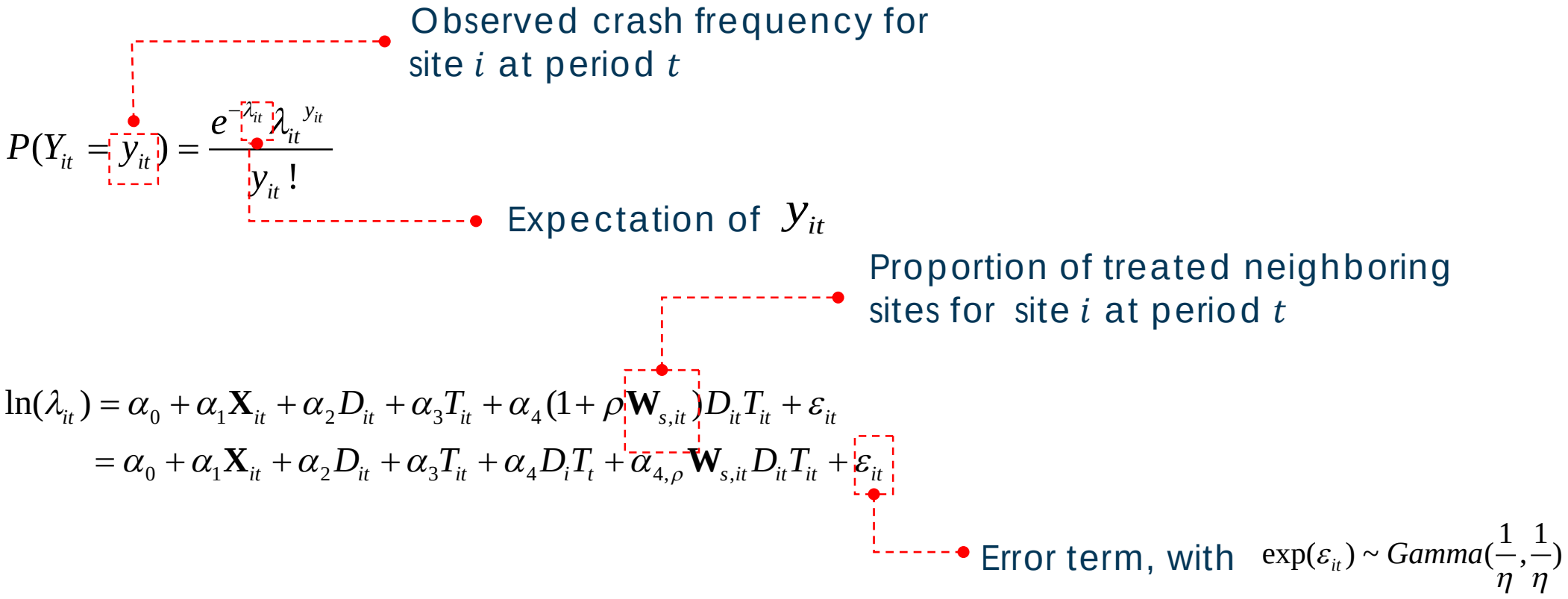
- Assume parallel trend of control and treatment sites.
- Use a spatial lag framework to address spatial spillover effect of the treatment,



Source: https://en.wikipedia.org/wiki/Difference_in_differences

Methods: SDID

- Model specification



Methods: SDID

- Average direct treatment effect for the treated (ADTT)

$$\tau_{ADTT} = \alpha_4$$

- Average spatial spillover effect (average indirect treatment effect, AITT)

$$\tau_{AITT} = \alpha_{4,\rho} \overline{\mathbf{W}_{s,it} D_{it}}$$

$$se(\tau_{AITT}) = \sqrt{Var(\tau_{AITT})} = \sqrt{Var(\alpha_{4,\rho})} \times \overline{W_{s,it} D_{it}}$$

Average spatial weight

- Average treatment effect for the treated

$$\tau_{ATT} = \tau_{ADTT} + \tau_{AITT} = \alpha_4 + \alpha_{4,\rho} \overline{\mathbf{W}_{s,it} D_{it}}$$

$$se(\tau_{ATT}) = \sqrt{Var(\tau_{ATT})} = \sqrt{Var(\alpha_4) + \overline{\mathbf{W}_{s,it} D_{it}}^2 Var(\alpha_{4,\rho}) + 2\overline{\mathbf{W}_{s,it} D_{it}} Cov(\alpha_4, \alpha_{4,\rho})}$$

Covariance between the two parameters

Results

- Modeling results for the integrated causal approach: PSM

		Logistic GAM		Logistic regression	
Variables		Coefficient	Std. Error	Coefficient	Std. Error
Intercept		3.70***	0.20	6.66***	0.36
Borough areas (base: Bronx & Brooklyn)	Manhattan	-0.83***	0.16	-0.86***	0.16
	Queens	-1.14***	0.15	-1.13***	0.14
	Staten Island	-2.69***	0.17	-2.71***	0.17
One-way street		-0.63***	0.12	-0.64***	0.12
Number of intersections		0.05***	0.01	0.05***	0.01
Number of lanes		-0.21***	0.04	-0.25***	0.04
Arterial street		-0.24*	0.12	-0.23*	0.11
Log (VMT)		-	-	-0.37***	0.05
Approximate significance of smooth terms					
		Effective degree of freedom	Chi. squared		
Smooth function of Log (VMT)		6.18	80.66***	-	-
AIC		2444		2463	

Statistical significance levels: *0.01 ≤ p-value < 0.05; **0.001 ≤ p-value < 0.01; *** p-value < 0.001

Results

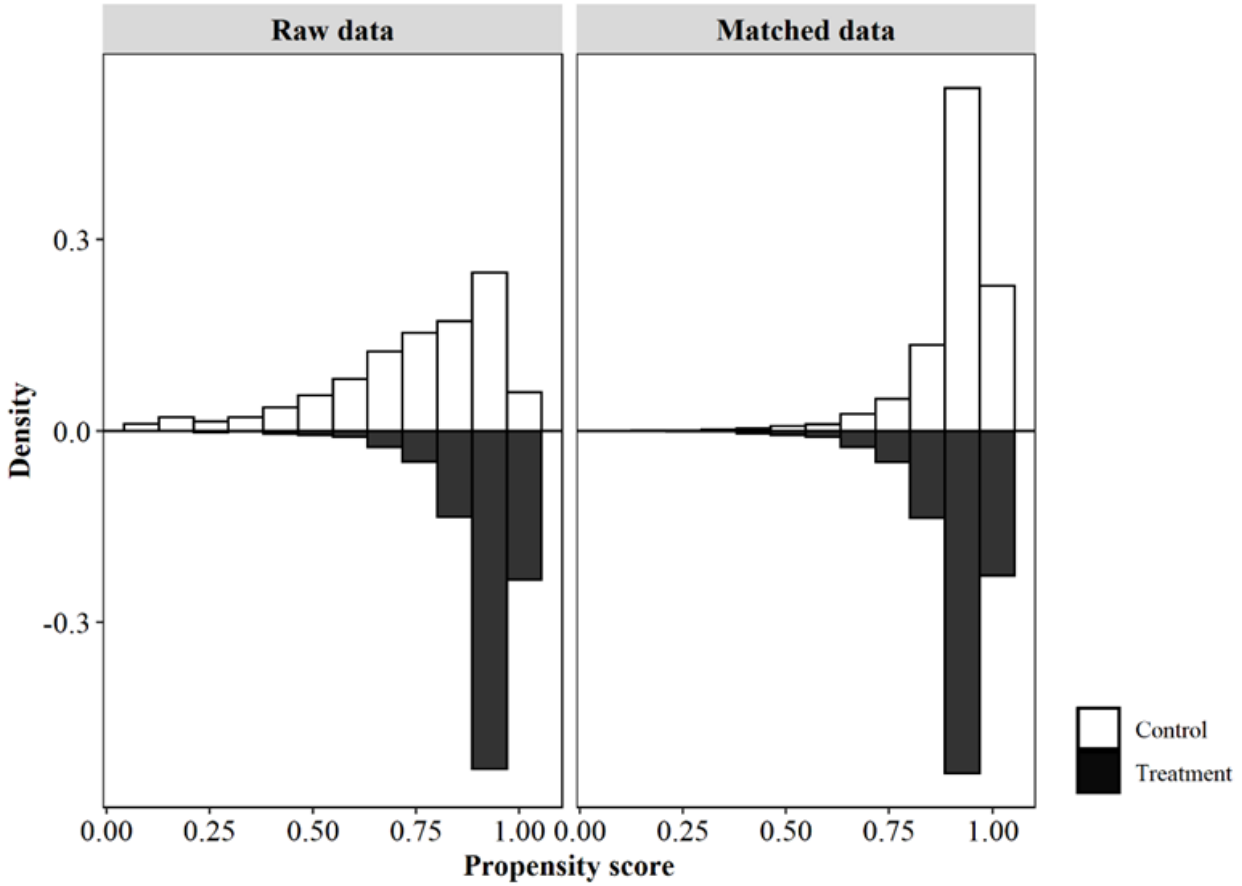
- Modeling results for the integrated causal approach: Balance statistics

Covariates	Raw data			Matched data		
	Mean of treatment sites	Mean of control sites	ASMD	Mean of treatment sites	Mean of control sites	ASMD
Manhattan	0.19	0.22	0.08	0.19	0.20	0.02
Queens	0.29	0.34	0.11	0.29	0.34	<0.10
Staten Island	0.07	0.24	0.71	0.07	0.05	0.07
One-way street	0.51	0.66	0.29	0.51	0.49	0.04
Arterial street	0.40	0.55	0.31	0.40	0.40	0.01
Number of intersections	10.52	8.05	0.18	10.17	10.41	0.02
Number of lanes	2.31	3.19	0.78	2.31	2.25	0.05
Log (VMT)	7.66	8.27	0.38	7.68	7.59	0.06

$$ASMD = \frac{\left|\mu_{w_{i0}\mathbf{x}_{i0}|D_{i0}=1} - \mu_{w_{i0}\mathbf{x}_{i0}|D_{i0}=0}\right|}{s_{w_{i0}X_{i0}|D_{i0}=1}} = \frac{\left|\frac{1}{n_1}\sum_{D_{i0}=1} w_{i0}X_{i0} - \frac{1}{n_0}\sum_{D_{i0}=0} w_{i0}X_{i0}\right|}{\sqrt{\frac{\sum_{i\in\{i:D_{i0}=1\}}(w_{i0}X_{i0} - \mu_{w_{i0}\mathbf{x}_{i0}|D_{i0}=1})^2}{n_1 - 1}}}$$

Results

- Modeling results for the integrated causal approach: Propensity score distributions



Results

- Modeling results for our integrated causal approach

		Fatal crashes		Injury crashes		PDO crashes	
		Coeff.	Std. Err	Coeff.	Std. Err	Coeff.	Std. Err
Intercept		-9.39***	0.64	-2.46***	0.09	-1.07***	0.09
Borough areas (base: Brooklyn & Bronx)	Manhattan	-0.33*	0.13	-	-	0.55***	0.03
	Queens	-0.40***	0.12	-0.46***	0.03	-0.29***	0.03
	Staten Island	-1.50***	0.33	-1.18***	0.05	-0.83***	0.05
One-way street		-	-	-0.04'	0.02	0.07**	0.02
Arterial street		-	-	-	-	0.08***	0.02
Number of intersections		0.02***	<0.01	0.03***	<0.01	0.03***	<0.01
Log (VMT)		0.58***	0.05	0.54***	0.01	0.50***	0.01
T_{it}		0.79	0.58	-0.14	0.07	0.06	0.08
D_{it}		1.84***	0.49	0.06	0.05	0.08	0.06
$D_{it}T_{it}$		-0.01	0.73	0.24	0.14	0.22	0.14
$W_{s,it}D_{it}T_{it}$		-1.10*	0.52	-0.19	0.12	-0.19	0.12
η		1.81*	0.78	1.32***	0.03	1.00***	0.02
AIC		3232.25		46841.11		69132.50	
Pseudo R-Squared		0.16		0.52		0.51	

Statistical significance levels: '0.05 ≤ p-value < 0.10; *0.01 ≤ p-value < 0.05; **0.001 ≤ p-value < 0.01; *** p-value < 0.001

Results

- Safety effectiveness of the speed limit reduction

Safety effectiveness	Causal approach	τ_{ADTT}		τ_{AITT}		τ_{ATT}	
		Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Fatal crash frequency	CG	-		-		-0.60	-
	PSM	-		-		-0.63*	0.31
	DID	-		-		-0.60*	0.33
	SDID	0.30	0.60	-0.68*	0.33	-0.50***	0.12
	PSM + DID	-		-		-1.06*	0.47
	PSM + SDID	-0.01	0.73	-0.96*	0.39	-0.97*	0.48
Injury crash frequency	CG	-		-		0.05	-
	PSM	-		-		0.18***	0.06
	DID	-		-		0.11	0.07
	SDID	0.16	0.14	-0.04	0.07	0.11	0.07
	PSM + DID	-		-		0.06	0.08
	PSM + SDID	0.24	0.14	-0.17	0.09	0.07	0.10
PDO crash frequency	CG	-		-		0.05	-
	PSM	-		-		0.22***	0.06
	DID	-		-		0.11	0.07
	SDID	0.18	0.14	-0.05	0.07	0.12	0.08
	PSM + DID	-		-		0.04	0.08
	PSM + SDID	0.22	0.14	-0.17	0.09	0.05	0.08

Conclusions

- Speed limit reduction is estimated to decrease the fatal crash frequency by 62.09% ($exp^{-0.97}$-1), likely due to the reduced impact speed of collisions.

- Spatial spillover effect of speed limit reduction is found to be significant.

- Insignificant impacts on injury and PDO crashes, likely due to less awareness in a low-speed environment.

Thank you!

Questions?

Contact:
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