

The Effect of ShotSpotter Technology on Police Response Times

Job Market Talk

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Motivation:

AI in Police Departments:

- Substitutes → License plate readers, facial recognition
- Complements → predictive 'hotspot' policing
- AI changes officer production function

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- Gunshot detection
- Rationale: only 12% of gunfire reported (Carr and Doleac, 2017) → method to respond to others
- 150+ cities nationwide

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Research Question:

How does the implementation of ShotSpotter technology affect Priority 1 911 call response times?

- How does a police officer's production function change s.t. it affects response?

Why would ShotSpotter affect response times?

Resource-Intensive:

- Respond to every detected gunfire
- Chicago: ~70 daily dispatches, 20 min.
- Priority 1 - equivalent to active shooter

Police Scarcity:

- Fixed amount of resources ⇒ trade-offs

Unintended consequences?

- Does this reallocation affect 911 call response times?

On an **average day** in Chicago,

there are roughly
**70 ShotSpotter-initiated
dispatches** that take **20
minutes** to investigate,
resulting in **75 hours of
officer time**.

Does this result in **unintended consequences**?

Why do we care about response times?

“If police can arrive within one minute of the commission of an offense, they are more likely to catch the suspect. Any later and the chances of capture are very small, probably less than one in ten.”- (David H. Baley 1996)

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Evidence:

- Lower response times results in:
 - Higher crime clearance (Blanes i Vidal and Kirchmaier 2018)
 - Less likelihood of an injury (DeAngelo et al. 2023)
- Response → important component of investigation (College of Policing 2013)
- Health implications
 - Delayed treatment → worse patient outcomes (Wilde, 2013, Avdic, 2016)

Summary of the Paper:

Setting:

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 - 2nd largest police force
 - 3rd largest city

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Empirical Strategy:

- Staggered difference-in-differences
 - Variation: ShotSpotter rollouts across police districts

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Main Results:

- When a civilian calls 911, a Priority 1 call experiences:
 - +1 minute Call-to-Dispatch (23%)
 - +2 minutes Call-to-On-Scene (13%)
 - Lower arrest probability (8%)

Contribution:

In-depth, causal analysis on the unintended consequences of a wide-spread police technology.

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Related Literature

ShotSpotter Specific

We unpack the effects of this wide-spread police technology.

Police Technology

Rapid Response

AI in Workforce

- Economics:
 - Use ShotSpotter as data for alternative crime/mistrust measure (Carr and Doleac 2018; Ang et. al 2021)
- Non-Economics:
 - Better accuracy, little crime impact or case resolution (Piza et al., 2023; Mares and Blackburn, 2012; Choi et al., 2014)

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Related Literature

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Police Technology

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AI in Workforce

Unlike others, we find costly unintended consequences of a police technology.

- Benefits of Police Technology:
 - Body Worn Cameras → lower use of force/complaints (Zamoff et al. 2021; Braga et al. 2022; Ferrazares 2023)
 - Predictive Policing → less crime (Mastrobuoni, 2020; Jabri, 2021; Heller et al., 2022)
 - Tactical Equipment → less crime (Bove and Gavrilova 2017; Harris et al. 2017))

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Related Literature

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Police Technology

Rapid Response

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We identify a determinant of higher response times, and can quantify at a micro-level.

- Lower Response Times:
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In-depth, causal analysis on the unintended consequences of a wide-spread police technology.

Related Literature

ShotSpotter Specific

The results imply that this artificial intelligence technology cannot replace police officers.

Police Technology

Rapid Response

- Substitutes:

- AI operates better than human managers (Hoffman et al., 2018)

AI in Workforce

- Complements:

- Human and algorithmic targeting work best together (Bhatt et al., 2023)

Background on Chicago Policing

Chicago Background:

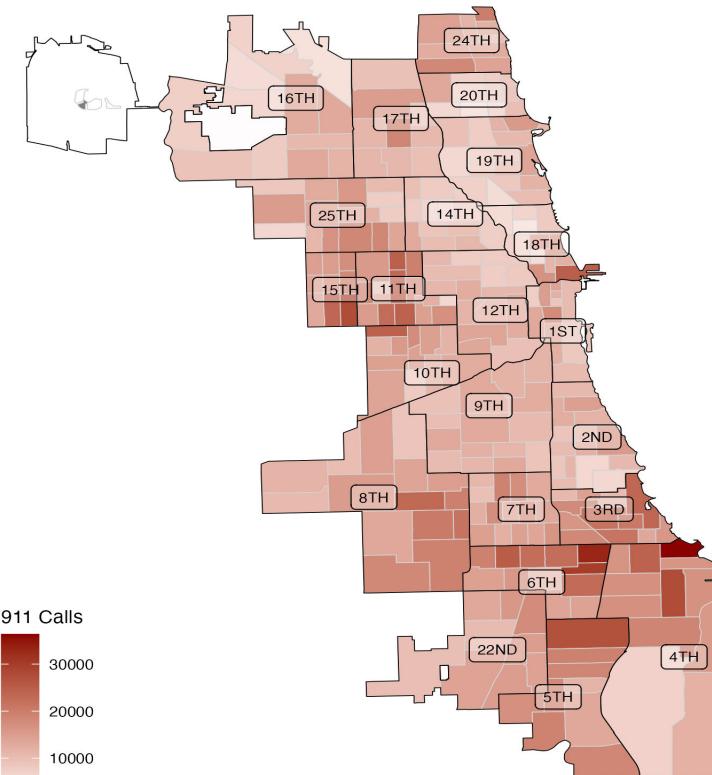
Chicago Geography:

- Chicago subset into 22 police districts (population ~100k)
 - Within districts are beats
 - Officers generally assigned within districts/beats to patrol

Chicago Crime:

- Chicago crime is localized
 - Gun-crime is localized to South/West sides

Number of Priority 1 911 Calls
Chicago (2016-2022)



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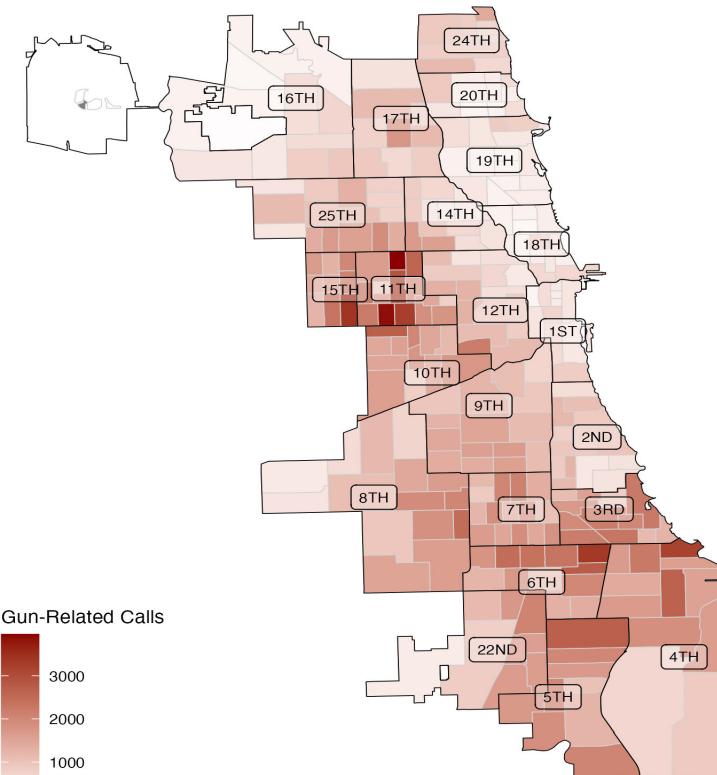
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Number of Gun-related 911 Calls
Chicago (2016-2022)



Policing in Chicago:

Police Officer Responsibilities:

- Patrol, respond to incidents, make arrests/stops, complete written reports
- Gathers info at traffic scenes—preliminary investigation
- Direct traffic
- Appear in court/give testimony

Police Time Allocation:

"From the minute you start your shift, radio is non stop calls until backlog. The whole shift you chase radio calls." - CPD Police Officer January 2023 (Indeed.com)

"Very busy be ready to answer up to 50 calls for service specialy during Summer season." - CPD Police Officer February 2023 (Indeed.com)

911 Dispatch Procedure in Chicago

911 Dispatch Procedure:

911 Dispatch Pipeline:

Call-to-Dispatch:

Call-to-On-Scene:

Arrest Made:

911 call ⇒ Dispatcher Assigns ⇒ Officer Travels ⇒ Officer Arrives

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Call-to-On-Scene

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Arrest Made:

- Only arrests in the 911 call pipeline: implication of rapid response

911 Call Priorities in Chicago:

Priority 1 (immediate dispatch):

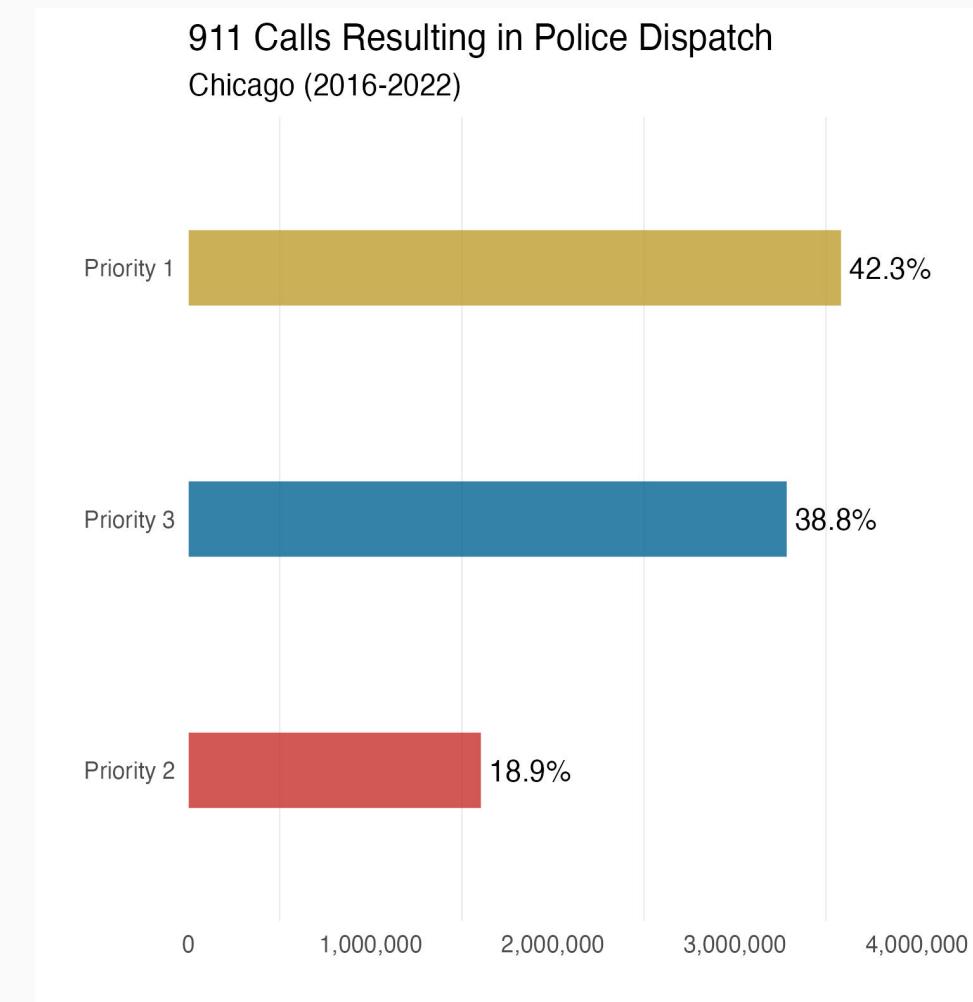
- Imminent threat to life, bodily injury, or major property damage/loss.
- Example: 'person with gun,' 'domestic battery'

Priority 2 (rapid dispatch):

- Time-sensitive, no threat to life.
- Example: 'suspicious auto'

Priority 3 (routine dispatch):

- Not time-sensitive.
- Example: 'parking violation'



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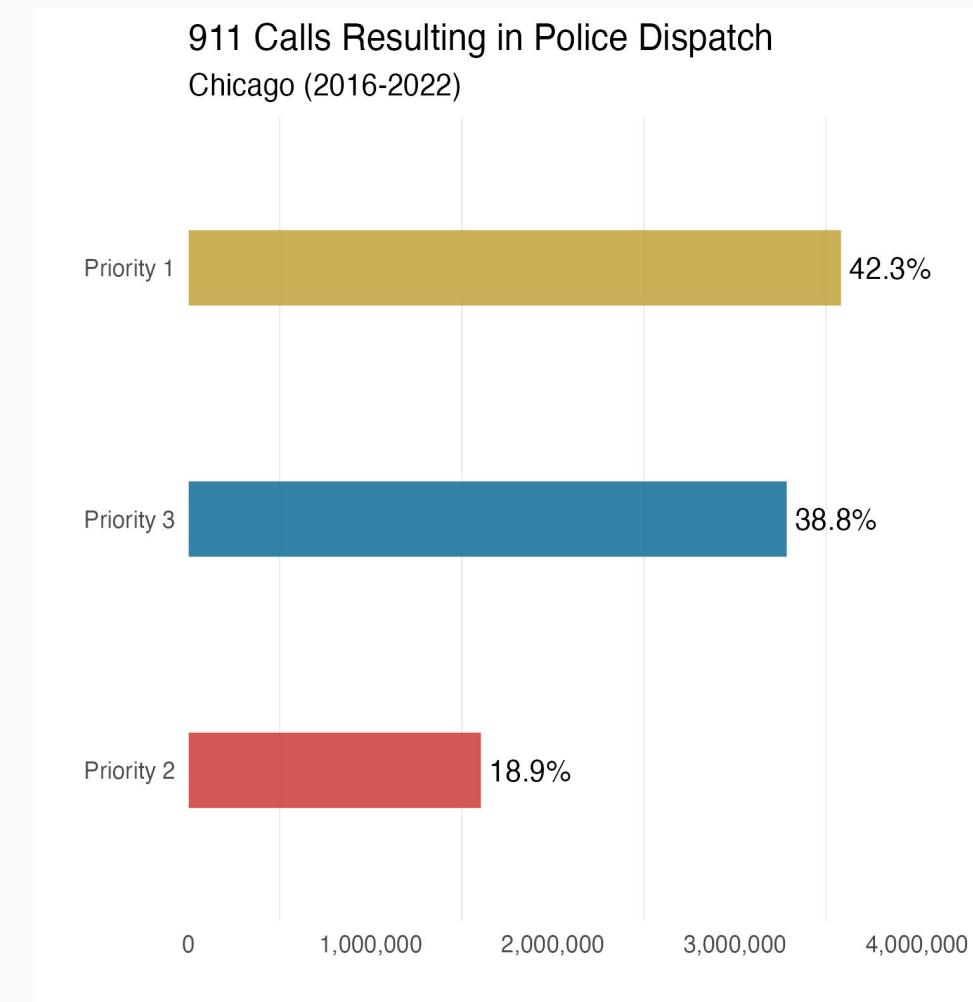
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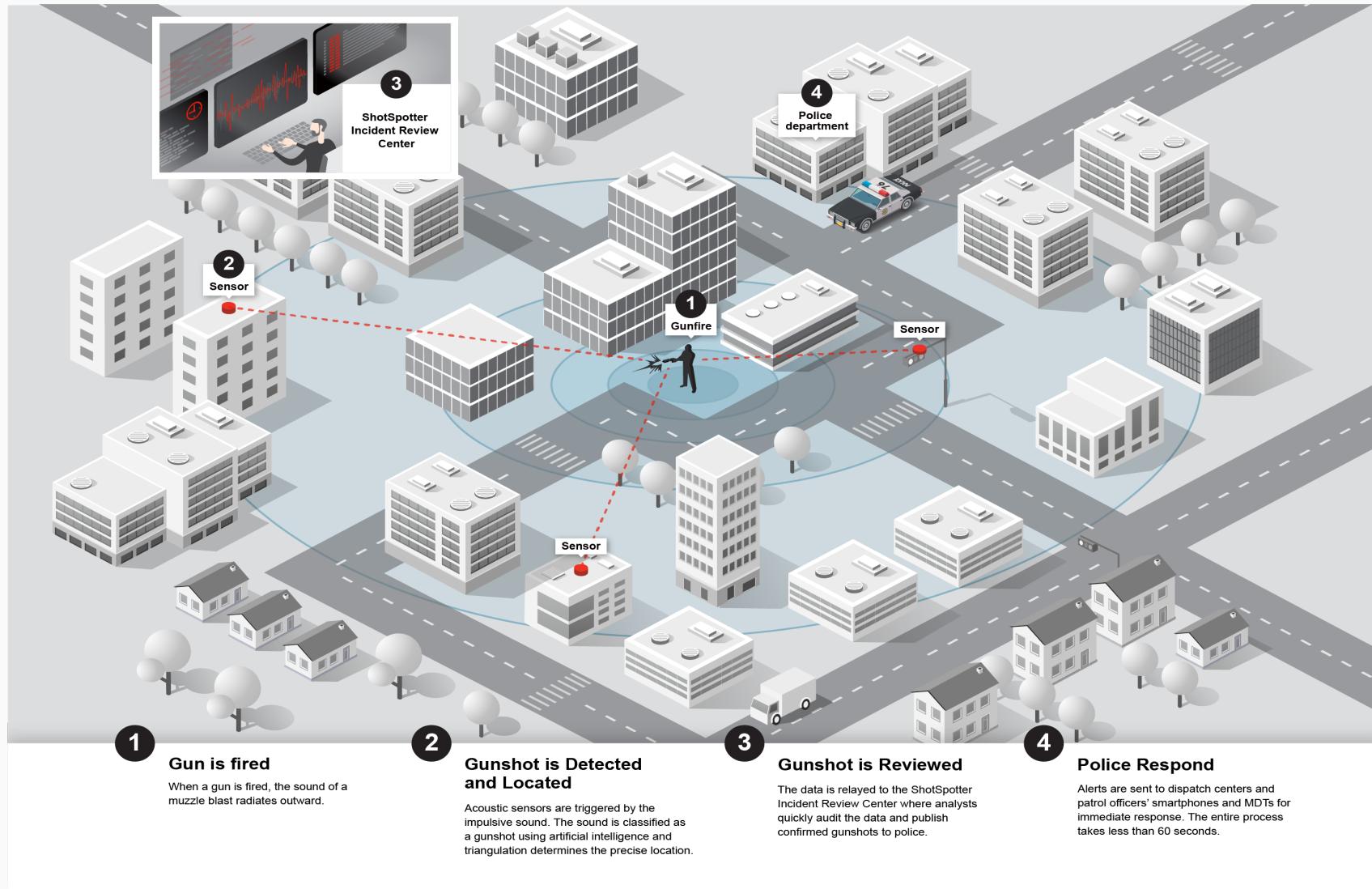
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ShotSpotter Technology in Chicago

ShotSpotter Functionality:



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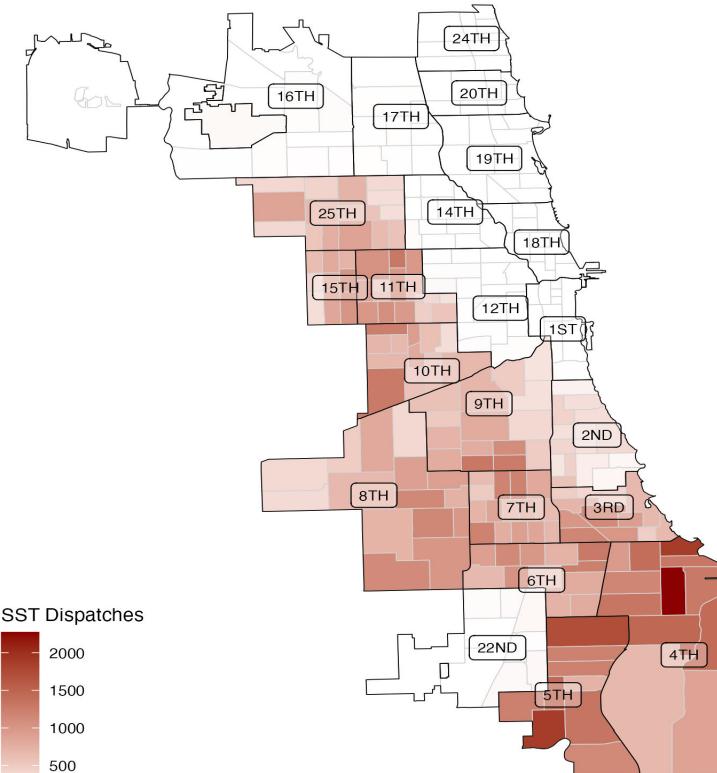
Staggered Rollout

- 12 of 22 police districts in 2017-2018
- Implemented with full coverage across districts
- Rational: respond to high gun-crime

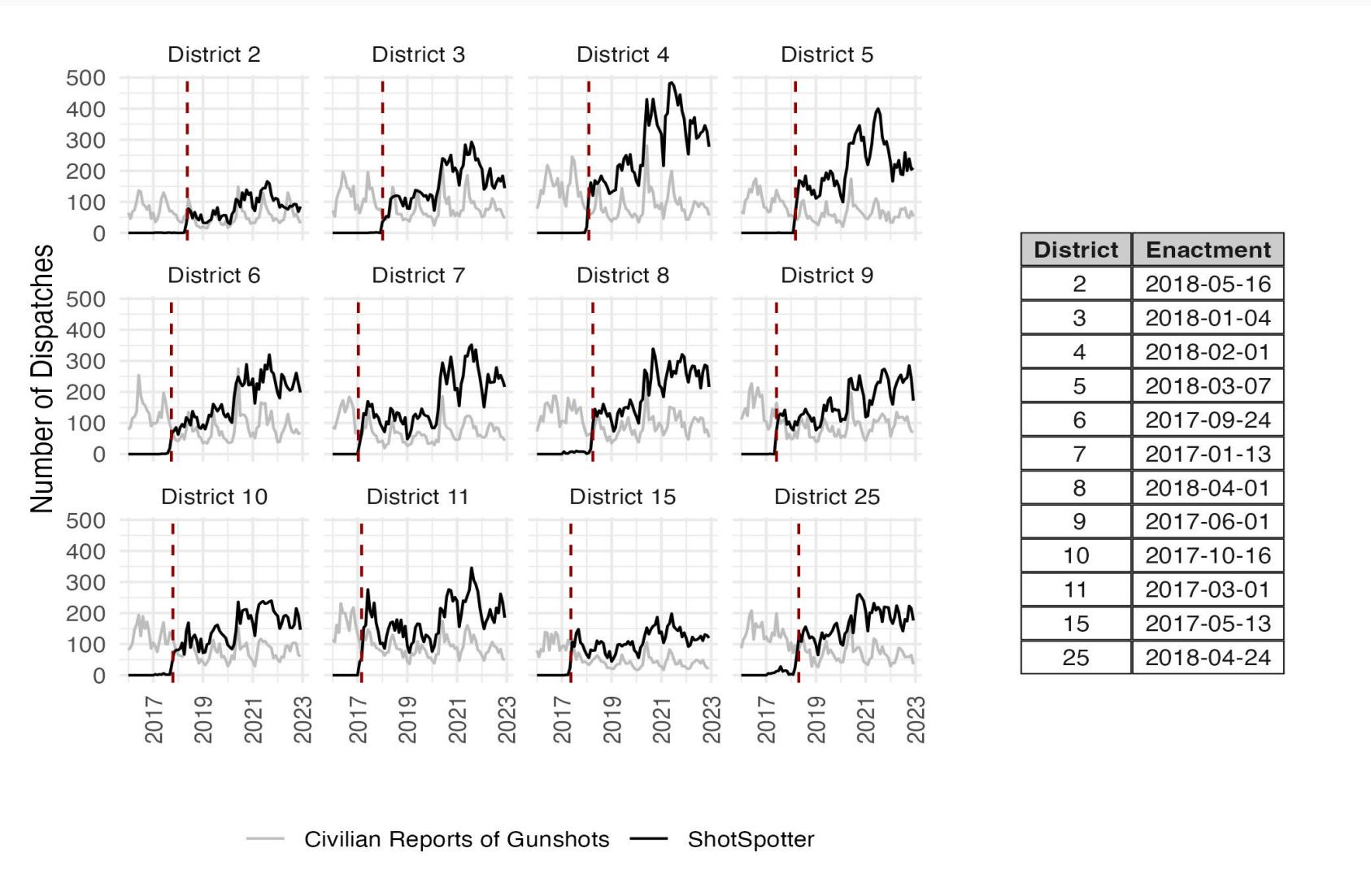
Administrative Background

- Priority 1 - same as active shooter
- Same officers responding as 911 call
- Additional: canvass 25 meter radius, add information

Number of ShotSpotter Dispatches
Chicago (2016-2022)



ShotSpotter Dispatch Trends (monthly):



Data and Empirical Strategy

Data and Sample Restrictions:

Data Overview:

- Priority 1 911 Calls (2016-2022) with police dispatch
- ShotSpotter dispatches ≠ 911 call
- Freedom of Information Act: 25 requests, 100+ emails/phone calls, 1 **lawsuit** against CPD

Sample Restrictions:

- Response time outliers 3+ Std.Dev. from mean (~1.7%)
- Negative response times (.03%)
- Days with celebratory gunfire: January 1/July 4/December 31

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	Mean	Std.Dev.	Min	Max	N
Call-to-Dispatch	281.89	436.53	2.00	3,111.00	3,582,560
	{4.70 mins}	{7.28 mins}	{0.03 mins}	{51.85 mins}	
Call-to-On-Scene	770.86	784.69	11.00	7,671.00	1,997,102
	{12.85 mins}	{13.08 mins}	{0.18 mins}	{127.85 mins}	

Estimation Strategy:

Specification (OLS):

$$\text{ResponseTime}_{cdt} = \beta \text{ShotSpotter}_{dt} + \eta_{\bar{c}} + \delta_d + \gamma \mathbb{X}_{f(t)} + \varepsilon_{cdt}$$

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Specification (OLS):

$$\text{ResponseTime}_{cdt} = \beta \text{ShotSpotter}_{dt} + \eta_c + \delta_d + \gamma \mathbb{X}_{f(t)} + \varepsilon_{cdt}$$

- $\text{ResponseTime}_{cdt}$ is call c in police district d in time t .
- ShotSpotter_{dt} is the binary treatment
- η_c is a call-type fixed effect
- δ_d is a police district-specific fixed effect
- $\mathbb{X}_{f(t)}$ is a vector of time-varying controls:
 - Hour-of-day and day-by-month-by-year
- Standard errors clustered by police district
- Intuitively, estimation of parameter ` β ` gives the average change in response times on days with ShotSpotter accounting for expected differences in districts/time/call-types.

Potential Threats to Identification:

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- Event studies
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3. Other policies that coincide that may affect response times:

- Strategic Decision Support Centers (SDSC) and Body-Worn Cameras (BWC)

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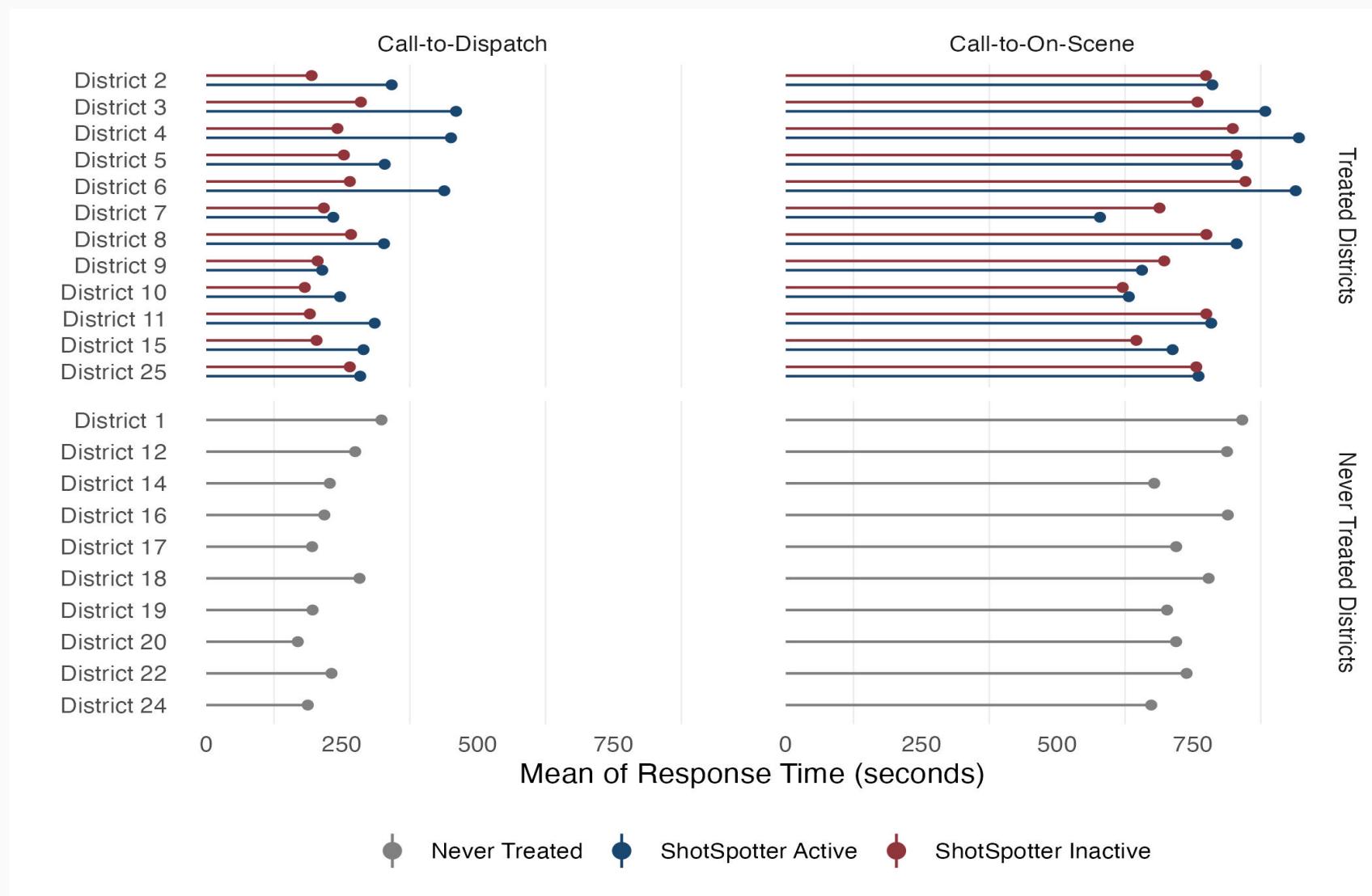
- Strategic Decision Support Centers (SDSC) and Body-Worn Cameras (BWC)

4. OLS with staggered rollouts:

- Two-stage difference-in-differences (Gardner 2021) similar to Borusyak et al. (2021)

Raw-Data Preview

Raw Data Preview:



Results

Effect on Call-to-Dispatch (seconds)

	Effect on Call-to-Dispatch (seconds)		
	(1)	(2)	(3)
ShotSpotter Activated	64.131*** (22.379)	72.063*** (22.356)	61.446*** (21.627)
Border District Activated			21.442 (16.503)
Mean of Dependent Variable	281.890	281.890	281.890
Observations	3,582,560	3,582,528	3,582,560
Wild Bootstrap P-Value	0.012	X	0.017
Gardner (2021) Robust	No	Yes	No
Clusters	22	22	22

Note:

* p < 0.1, ** p < 0.05, *** p < 0.01

Standard errors clustered by district. OLS estimates unless noted. Border District Activated is binary for a police district adjacent to a ShotSpotter district.

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Effect on Call-to-On-Scene (seconds)

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ShotSpotter Activated	102.682*** (28.724)	120.389*** (27.913)	100.986*** (28.099)
Border District Activated			24.178 (17.847)
Mean of Dependent Variable	770.863	770.863	770.863
Observations	1,997,102	1,997,076	1,997,102
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Effect on Arrest Likelihood (percent)

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	Gun-Relation			Most Frequent Arrest Types		
	Pooled	Gun	Non-Gun	Domestic Disturbance	Domestic Battery	Robbery
	(1)	(2)	(3)	(4)	(5)	(6)
ShotSpotter Activated	-0.221*** (0.063)	-0.157 (0.189)	-0.221*** (0.066)	-0.829*** (0.241)	-0.281** (0.123)	-0.303 (0.177)
Mean of Dependent Variable	2.449	3.355	2.361	6.110	2.021	4.185
Observations	3,582,560	317,937	3,264,623	224,022	675,025	270,735
Wild Bootstrap P-Value	0.001	0.412	0.003	0.003	0.049	0.109
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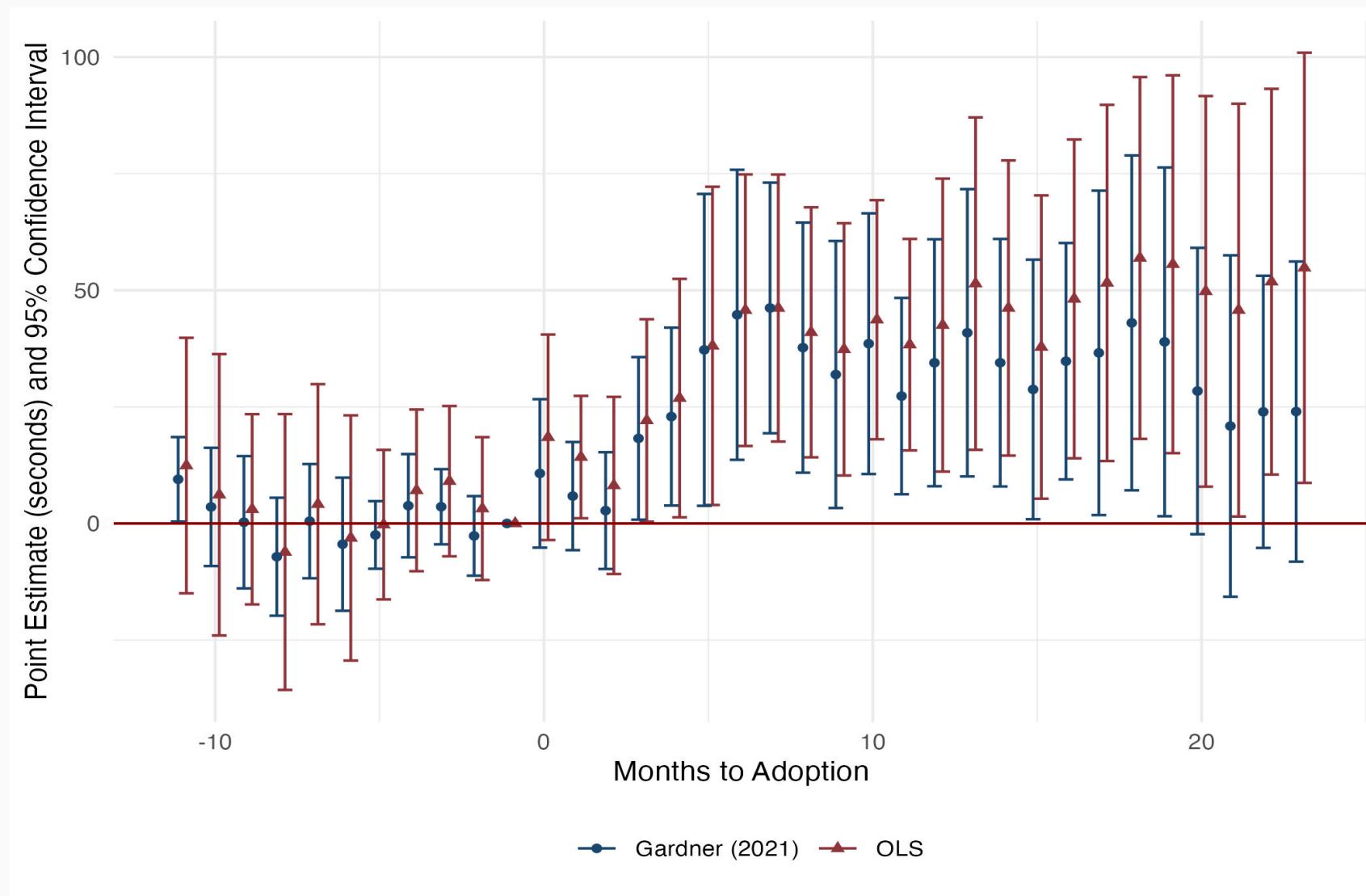
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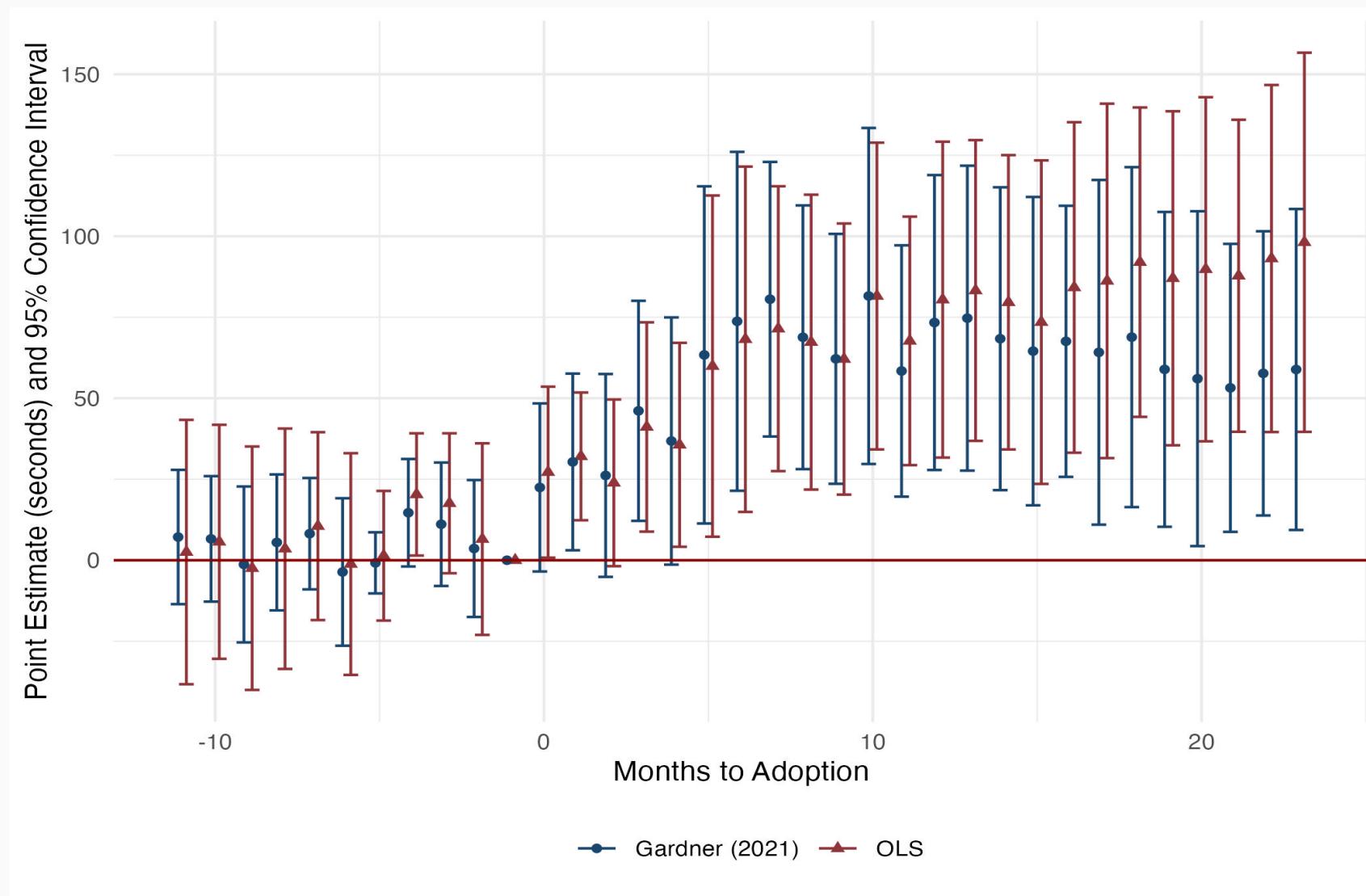
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Standard errors clustered by district.

Dynamic Effects: Call-to-Dispatch (seconds)



Dynamic Effects: Call-to-On-Scene (seconds)



Robustness:

Main Results:

- Leave-one-out analysis - [See Figure](#)
 - Both OLS/Gardner (2021)
- Sample restrictions - [See Figure](#)
 - Omit 2020 (Covid-19)
 - Omit 'Shots Fired' calls
 - Reintroduce outliers
 - Reintroduce omitted days
 - Omit never-treated
- For arrests:
 - Logistic regression - [See Figure](#)
- Control for CPD initiatives - [See Table](#)
 - Body-Worn Cameras
 - Strategic Decision Support Centers
- Sensitivity analysis - [See Figure](#)
 - Rambachan and Roth (2023)
 - Relax parallel trends

Mechanism: ShotSpotter Incapacitates Officers

Potential Mechanism: Time Constraint

1. Extensive Margin: Estimate most resource-constrained times

- Split by police-district median number of officer hours
- Separate by shift-type

2. Intensive Margin: Use ShotSpotter dispatches as intensity measure

- Using the number of ShotSpotter dispatches as our identifying variation, we estimate the marginal effect of an extra ShotSpotter dispatch:

$$\text{ResponseTime}_{cdt} = \beta \text{NumberSSTDispatches}_{dt} + \eta_c + \delta_d + \gamma \mathbb{X}_{f(t)} + \varepsilon_{cdt}$$

- $\text{NumberSSTDispatches}_{dt}$ is number of ShotSpotter dispatches in a police-district
- Restrict to only treated periods

Extensive Margin: Less Officers (seconds)

	Officer Availability		
	Pooled	> Median	<= Median
<i>Panel A: Call-to-Dispatch</i>			
ShotSpotter Activated	64.131*** (22.379)	33.661** (13.563)	88.896*** (29.255)
Mean of Dependent Variable	281.890	239.316	324.409
Observations	3,582,560	1,790,130	1,792,430
<i>Panel B: Call-to-On-Scene</i>			
ShotSpotter Activated	102.682*** (28.724)	59.737** (21.193)	137.872*** (37.072)
Mean of Dependent Variable	770.863	711.092	828.977
Observations	1,997,102	984,511	1,012,591

Note:

* p < 0.1, ** p < 0.05, *** p < 0.01

Standard errors clustered by district (22). Estimates are reported in seconds. Medians are within-district.

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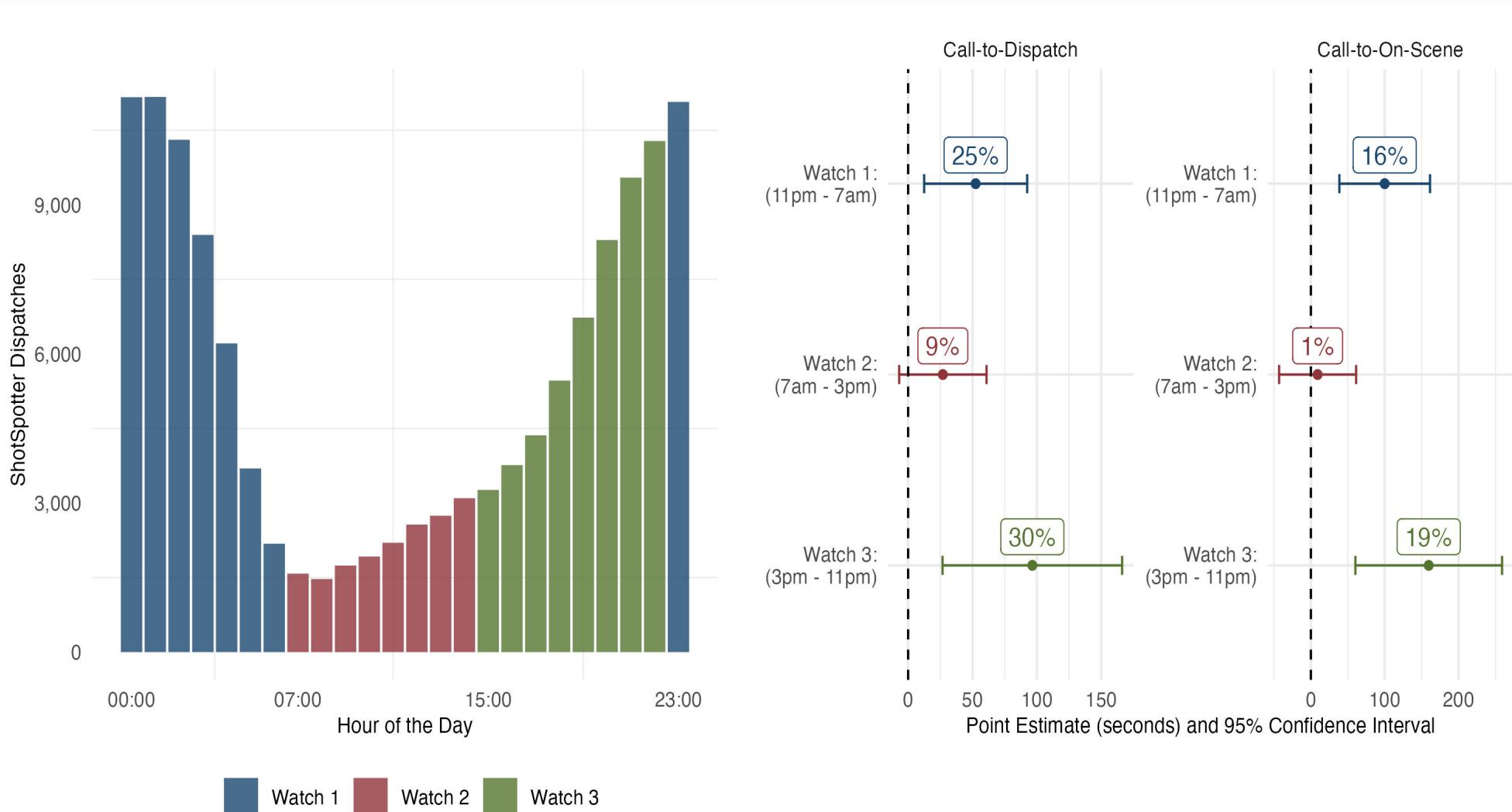
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Extensive Margin: Shift Times



Intensive Margin: ShotSpotter Dispatches

	Officer Availability		
	Pooled	> Median	<= Median
<i>Panel A: Call-to-Dispatch</i>			
Number SST Dispatches	5.815*** (1.395)	4.368*** (1.161)	5.017*** (0.840)
Mean of Dependent Variable	291.300	242.505	340.021
Observations	2,958,754	1,478,258	1,480,496
<i>Panel B: Call-to-On-Scene</i>			
Number SST Dispatches	7.704*** (1.749)	6.063*** (1.302)	6.153*** (1.104)
Mean of Dependent Variable	771.964	701.935	842.234
Observations	1,732,479	867,736	864,743

Note:

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Heterogeneity

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- Analyze specific call-types (call-codes) for the most frequent offenses
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2. Split by priority of call

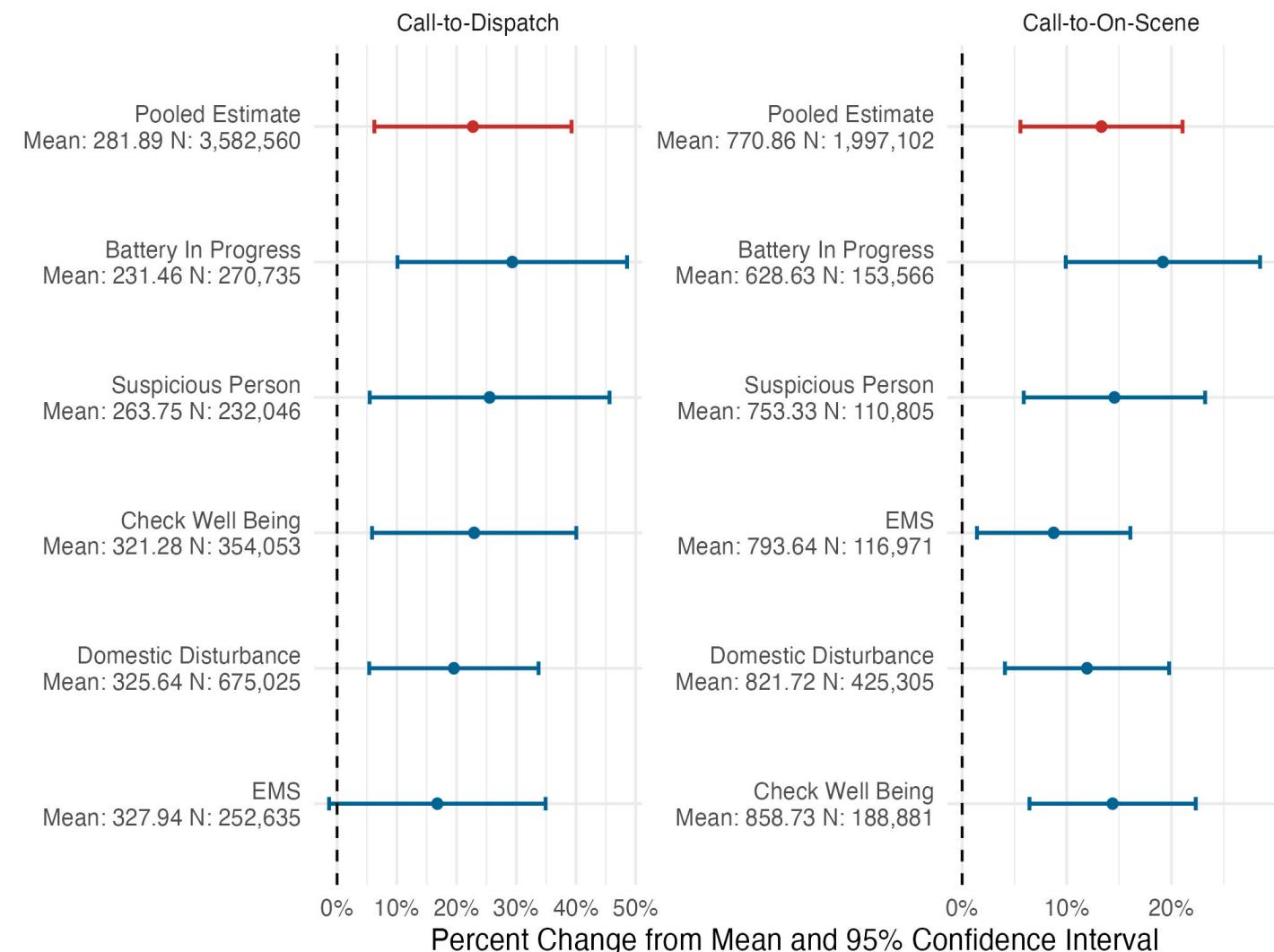
- A 'trickle down' effect in Priority 2
 - Suggestive for Priority 3
- No time for high priority ⇒ no time for lower priorities
- Lends to the idea that officers are facing more responsibilities than they can handle
 - Incapacitation effect

Priority and Call-type Heterogeneity:

Priority 1

Priority 2 (Rapid)

Priority 3 (Routine)

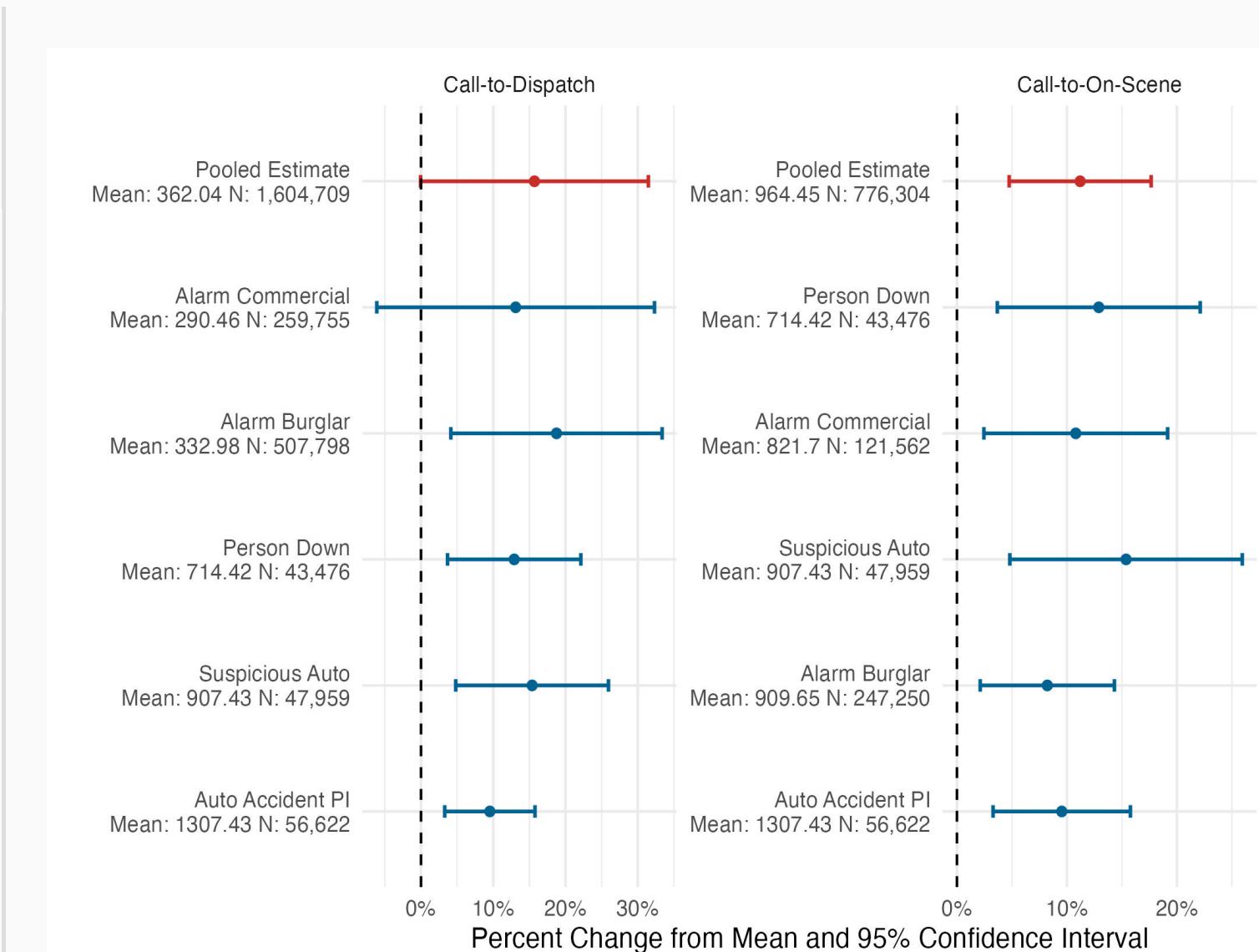


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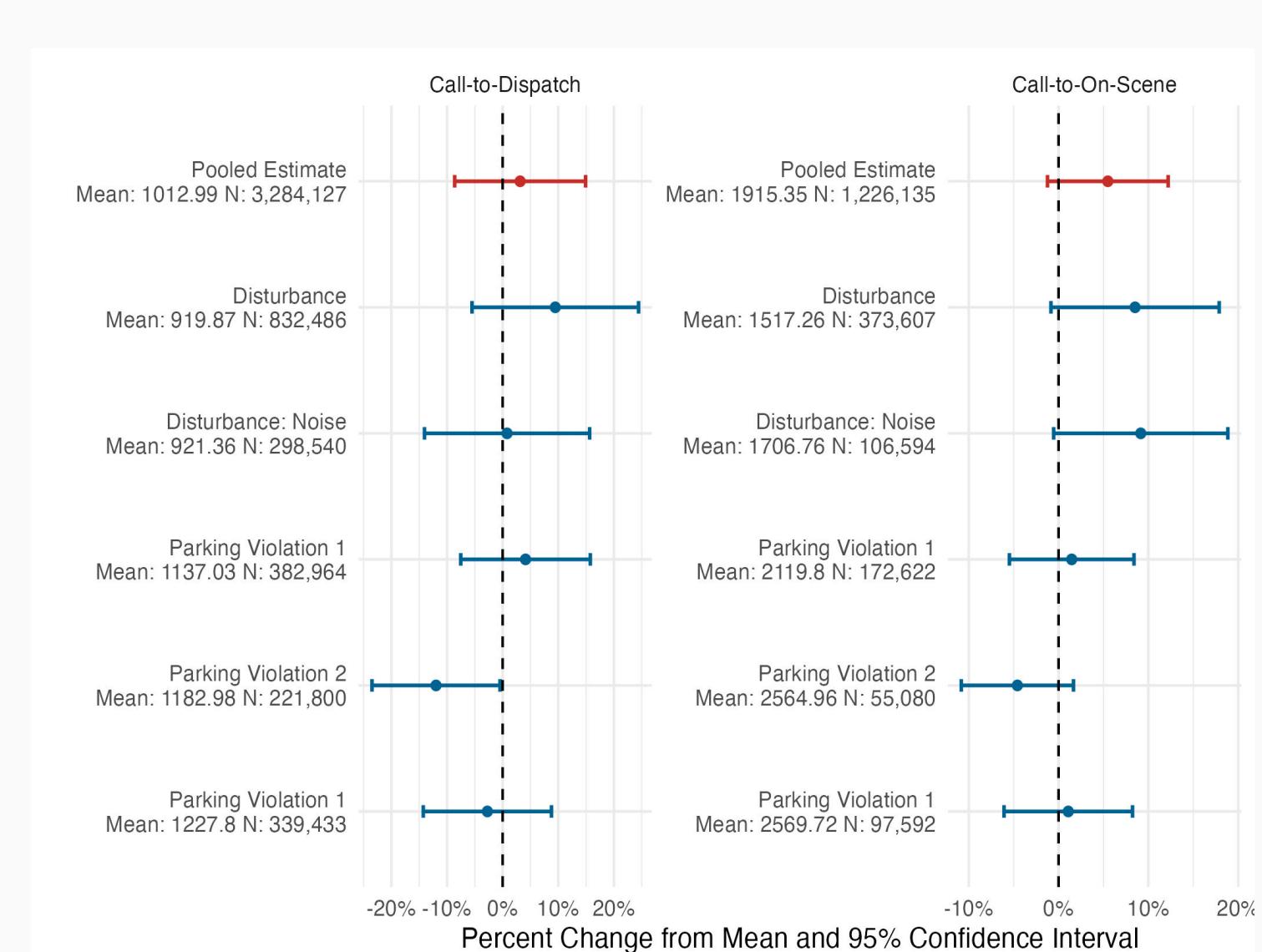


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Priority 3 (Routine)



How does ShotSpotter affect 911 injury likelihood?

Does ShotSpotter affect 911 injury likelihood?

Analysis:

- Analyze the probability of a victim injury on a 911 call
 - Faster response \Rightarrow less injury (DeAngelo et al. 2023)

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Results:

- Suggestive (not conclusive!) evidence of lower injury probability for gun-related calls
 - ShotSpotter may corroborate gun-related 911 calls
 - Provide more intelligence
- No effect on non-gun-related calls
 - Cannot rule out increases

Effect on Victim Injury Likelihood (percent):

	Likelihood of Victim Injury (percent)		
	Pooled	Gun Dispatch	Non-Gun Dispatch
	(1)	(2)	(3)
ShotSpotter Activated	-0.062 (0.051)	-0.422* (0.211)	-0.007 (0.054)
Mean of Dependent Variable	2.990	4.185	2.874
Observations	3,582,560	317,937	3,264,623
Wild Bootstrap P-Value	0.123	0.114	0.751
Clusters	22	22	22

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Victim injury is a binary equal to one if a 911 call ends with a victim being injured.

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Conclusion:

Contribution:

- An in-depth analysis on unintended consequences of ShotSpotter
- Find a determinant of response times

Main Findings: Longer Response

- Call-to-Dispatch (+1 minute/ 23%)/ Call-to-On-Scene (+2 minutes/ 13%)
 - Longer response times ⇒ lower arrest likelihood (8% decrease)

Mechanism: Incapacitation

- More officers needed to mitigate unintended consequences
- Back-of-the-envelope: 2x more officers needed

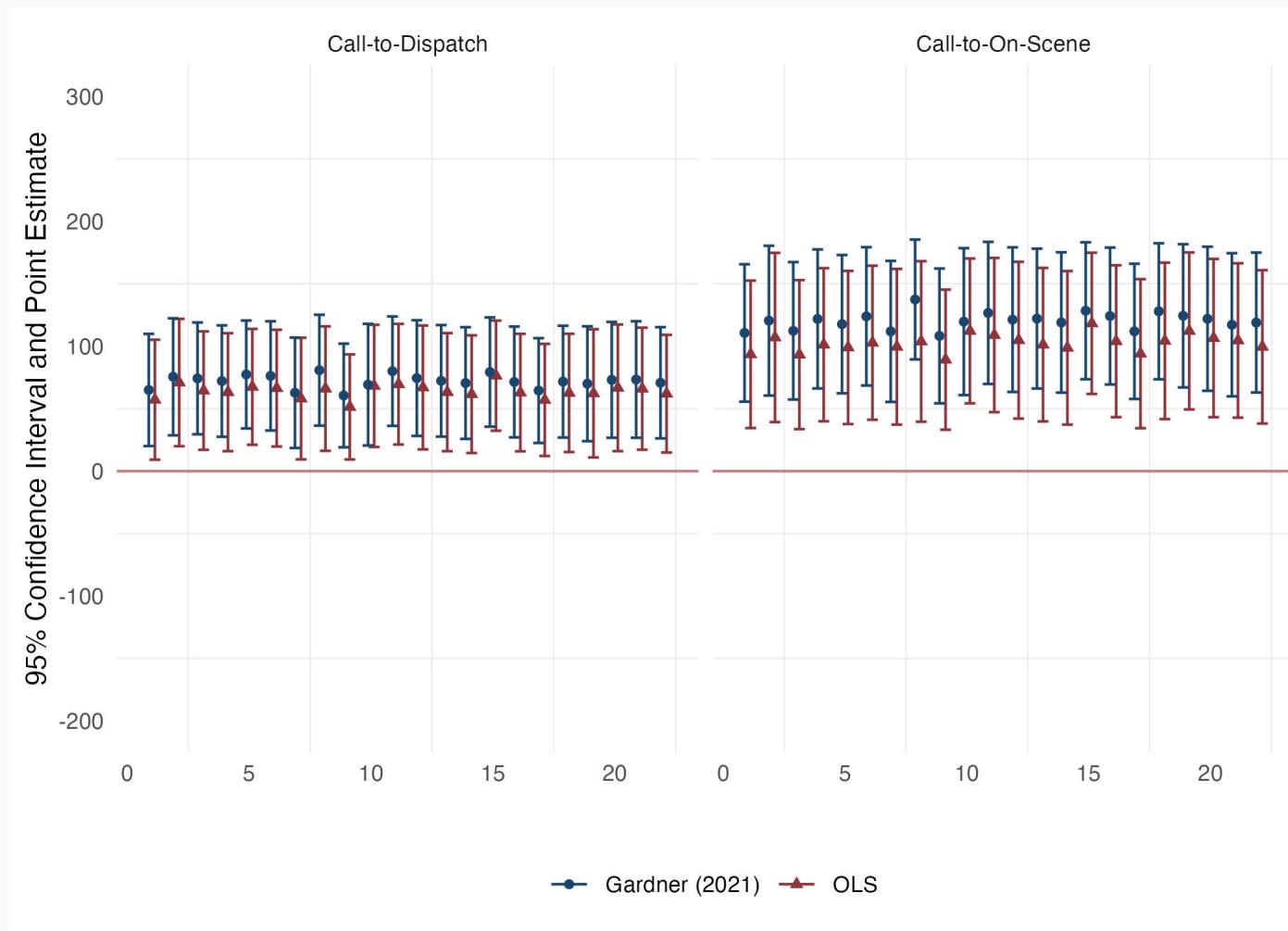
Thank you

Lawsuit

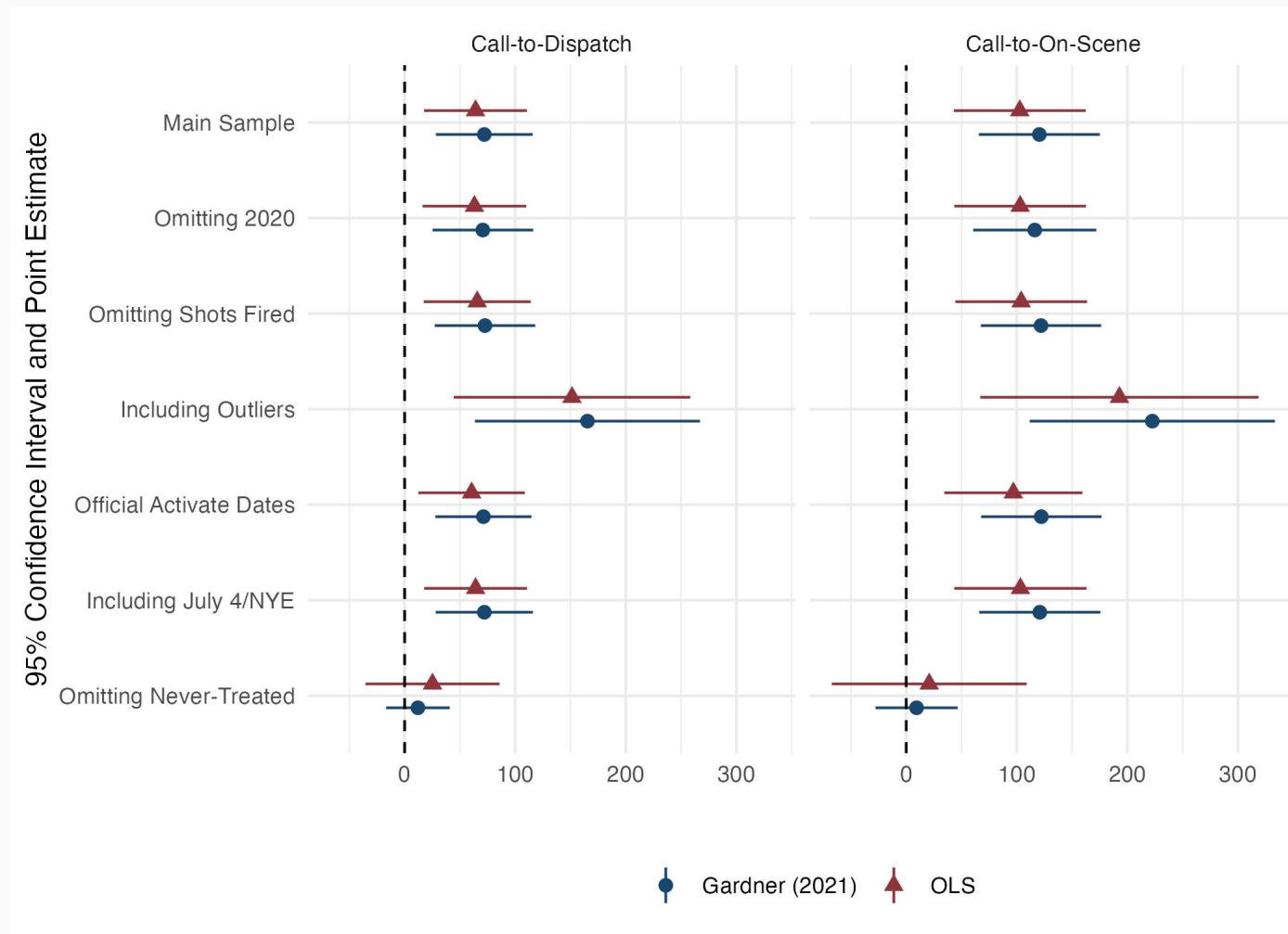
<p>Hearing Date: 9/21/2023 9:30 AM Location: Court Room 2402 Judge: Price Walker, Allen</p> <p>FILED DATE: 5/24/2023 2:20 PM 2023CH05086</p>	<p>FILED 5/24/2023 2:20 PM IRIS Y. MARTINEZ CIRCUIT CLERK COOK COUNTY, IL 2023CH05086 Calendar, 3 22865224</p> <p>IN THE CIRCUIT COURT OF COOK COUNTY, ILLINOIS COUNTY DEPARTMENT, CHANCERY DIVISION</p> <p style="text-align: center;">2023CH05086</p> <p>MICHAEL TOPPER,)) Plaintiff,)) v.)) CHICAGO POLICE DEPARTMENT,)) Defendant.)</p>	<p>COMPLAINT</p> <p>NOW COMES Plaintiff MICHAEL TOPPER, by the undersigned attorneys Loevy & Loevy, and brings this suit to overturn CHICAGO POLICE DEPARTMENT's willful violation of the Illinois Freedom of Information Act. TOPPER made a FOIA request to CPD for arrest records. Even though TOPPER provided CPD multiple opportunities to remedy its noncompliance, CPD refused to comply with FOIA. In support of the Complaint, TOPPER states as follows:</p> <p>INTRODUCTION</p> <p>1. Pursuant to the fundamental philosophy of the American constitutional form of government, it is the public policy of the State of Illinois that all persons are entitled to full and complete information regarding the affairs of government and the official acts and policies of those who represent them as public officials and public employees consistent with the terms of the Illinois Freedom of Information Act ("FOIA"). 5 ILCS 140/1.</p> <p>2. Restraints on access to information, to the extent permitted by FOIA, are limited</p>
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Back to Data

Leave-one-out



Robustness Across Samples



Effect on Arrest Likelihood (Logit)

	Effect on Arrest Likelihood (Logit)					
	Gun-Relation			Most Frequent Arrest Types		
	Pooled	Gun	Non-Gun	Domestic Disturbance	Domestic Battery	Robbery
	(1)	(2)	(3)	(4)	(5)	(6)
ShotSpotter Activated	-0.085*** (0.022)	-0.041 (0.060)	-0.092*** (0.024)	-0.144*** (0.040)	-0.130** (0.055)	-0.077* (0.042)
Mean of Dependent Variable	0.025	0.034	0.024	0.062	0.020	0.042
Observations	3,523,729	312,283	3,205,792	220,976	668,286	266,890
Clusters	22	22	22	22	22	22

Note:

* p < 0.1, ** p < 0.05, *** p < 0.01

Standard errors clustered by district. Estimates are not scaled by 100.

[Back to Robustness](#)

Controlling for BWC and SDSC (Dispatch)

	SDSC Controls			BWC Controls		
	Omitting Districts 7 and 9					
	(1)	(2)	(3)	(4)	(5)	(6)
ShotSpotter Activated	75.429*** (25.028)	71.817*** (22.497)	84.736*** (26.894)	90.334*** (22.057)	61.256*** (20.988)	71.856*** (22.523)
SDSC Activated	-36.742** (16.585)		-48.221** (16.930)			
BWC Activated					-30.735 (20.755)	
Mean of Dependent Variable	281.890	281.890	289.018	289.018	281.890	281.890
Observations	3,582,560	3,582,528	3,198,525	3,198,500	3,582,560	3,582,528
Wild Bootstrap P-Value	0.006		0.004		0.010	
Gardner (2021) Robust	X		X		X	

Note:

* p < 0.1, ** p < 0.05, *** p < 0.01

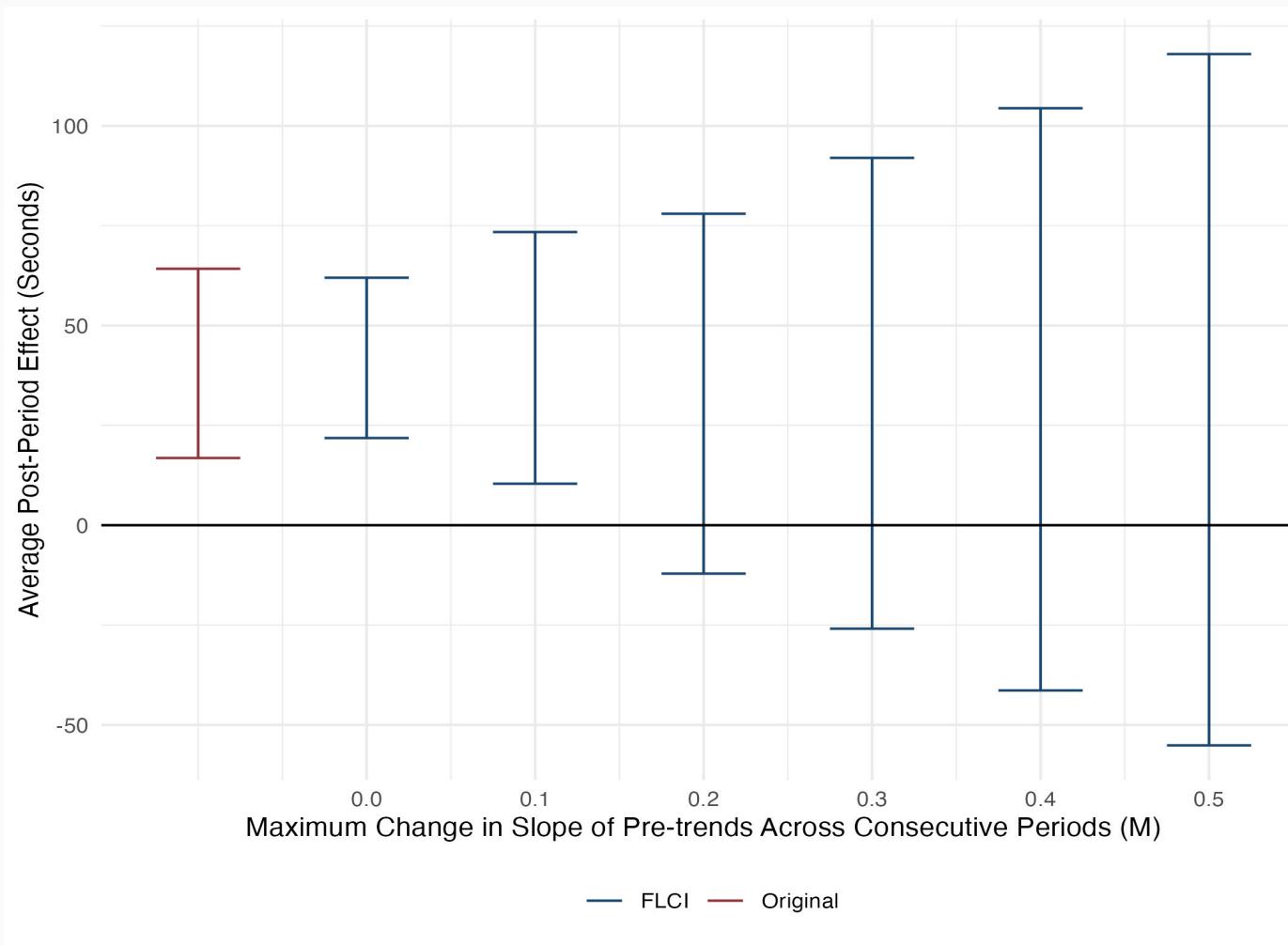
Controlling for BWC and SDSC (On-Scene)

	SDSC Controls			BWC Controls		
	Omitting Districts 7 and 9					
	(1)	(2)	(3)	(4)	(5)	(6)
ShotSpotter Activated	120.530*** (30.436)	120.080*** (28.141)	127.822*** (32.875)	145.931*** (24.339)	98.403*** (27.843)	120.214*** (28.246)
SDSC Activated	-60.324*** (18.978)		-71.208*** (20.381)			
BWC Activated					-40.821 (26.223)	
Mean of Dependent Variable	770.863	770.863	790.897	790.897	770.863	770.863
Observations	1,997,102	1,997,076	1,762,676	1,762,656	1,997,102	1,997,076
Wild Bootstrap P-Value	0.002		0.001		0.002	
Gardner (2021) Robust	X		X		X	

Note:

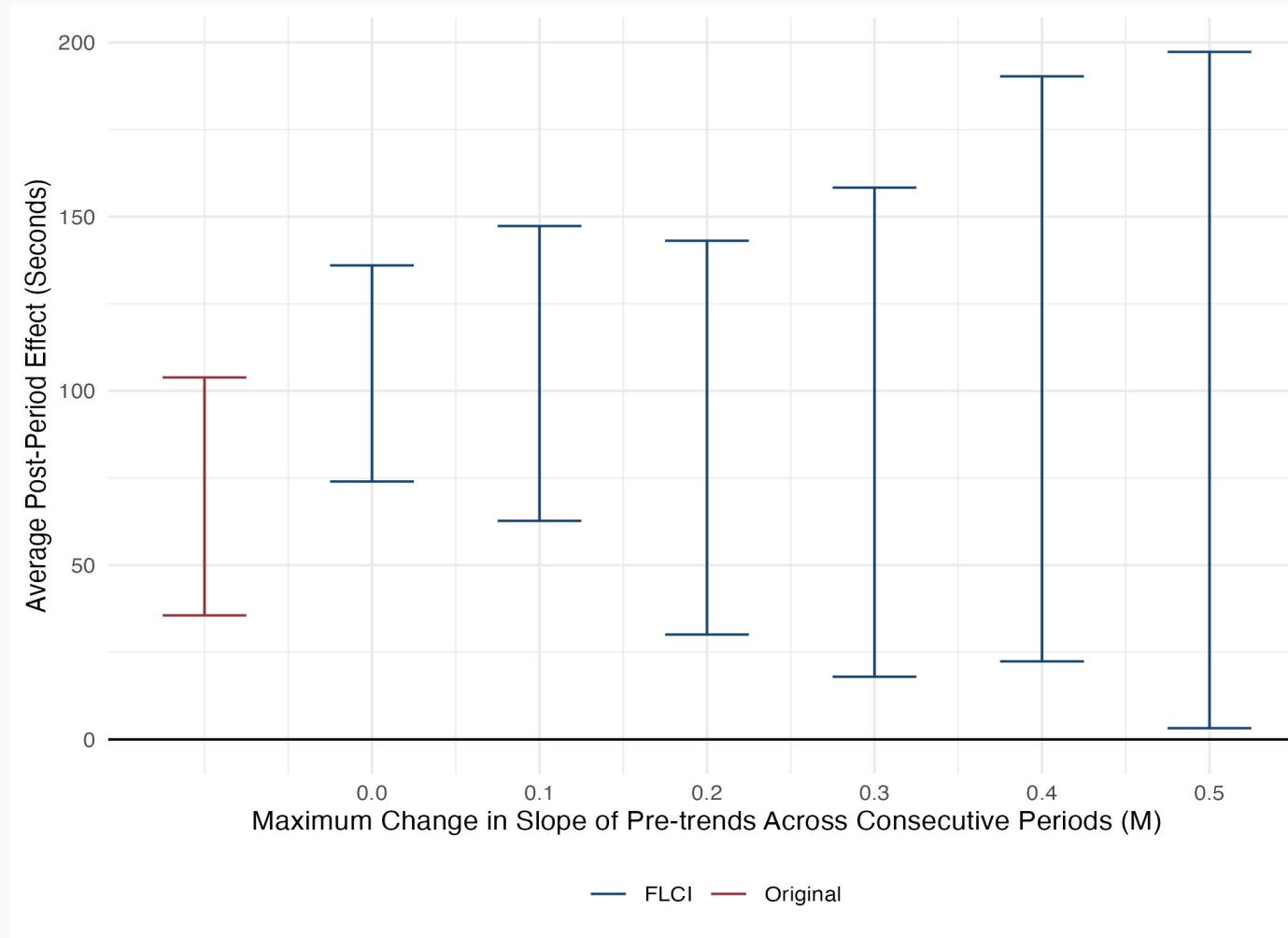
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Rambachan and Roth 2023: Sensitivity Analysis



Back to Robustness

Rambachan and Roth 2023: Sensitivity Analysis



Back to Robustness