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The impact of weather on the racial composition of traffic stop and citation issuance in the United States

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ABSTRACT

We analyze how adverse weather influences the racial composition of traffic stops and the issuance of citations within the context of administrative discretion. The behavior of police officers and drivers may be affected by weather, leading to a change in the composition of stopped drivers. If changes in racial composition are due to police officers choosing to forego traffic stops because those are more costly in wet conditions, it could indicate racial bias. Based on data from 37 city and 11 state police departments, our analysis reveals that the racial composition of drivers stopped and the probability of a citation being issued are not independent of adverse weather conditions, especially for state agencies. These findings contribute to the existing literature on factors influencing police–citizen interactions and provide a foundation for investigating the potential connections among weather, administrative discretion, and racial bias.

KEYWORDS

Administrative discretion; precipitation; police; racial bias; discrimination

Introduction

The Police-Public Contact Survey (PPCS) reports that 11.1% of United States (U.S.) residents were subject to a police-initiated contacts in 2018 (Harrell & Davis, 2020). Vehicular traffic stops are the most common of those encounters with about 20 million stops occurring every year (Davis et al., 2018; Pierson et al., 2020). The high frequency of those stops makes them one of the most prevalent interactions between citizens and governments (Federman, 2022; Hartley et al., 2023). Thus, experiences during stops shape citizens' perspectives on the fairness, integrity, and legitimacy of government (Epp et al., 2014; Lerman & Weaver, 2014). Police officers exercise considerable discretion when enforcing traffic laws. During the last decades, this discretion has come under increased scrutiny with focus on the racial disparities in terms of the frequency of and actions during stops (Baumgartner et al., 2018; Cobbina-Dungy & Jones-Brown, 2021; Doyle & Nembhard, 2021; Epp et al., 2014; Rice & White, 2010).

Administrative discretion broadly refers to the authority granted to individuals to make decisions within specific contexts. This authority is crucial for the effective functioning of frontline workers, such as police officers and other street-level bureaucrats, making them key agents in policy execution (Barnes & Henly, 2018; Gofen, 2014; Hupe & Hill, 2007; Lipsky, 1980; Maynard-Moody & Musheno, 2012). While the significance of discretion in policy implementation is widely acknowledged, its impact on policy outcomes has been assessed from two viewpoints (Thomann et al., 2016, 2018). On the one hand, top-down approaches view deviations from written policies as control issues, suggesting that flexibility in policy interpretation can lead to discrepancies between intended and actual outcomes (Howlett, 2004). On the other hand, bottom-up approaches emphasize the vital role of frontline workers' discretion in the effective implementation of policies (Lipsky, 1980; Sabatier,

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1986). Recent studies have attempted to reconcile these viewpoints, demonstrating that discretion can have both positive and negative effects on policy outcomes (Chang & Brewer, 2023).

The potential negative impacts of administrative discretion, particularly in the enforcement of traffic laws, have sparked a debate among the public and academics. Some scholars argue that discretion contributes to racial bias in traffic stops and citations, whereas others do not find any evidence of racial discrimination (Durlauf & Heckman, 2020; Fryer, 2019; Knox & Mummolo, 2020). Adding a new dimension to this debate, we explore the impact of adverse weather on administrative discretion in policing. Specifically, we assess the effects of adverse weather on the probability of (1) a stopped driver being Black and (2) the issuance of citations to drivers of different races during a traffic stop.

Our rationale draws support from research providing evidence that precipitation and temperature impact individuals' happiness and behavior (Horanont et al., 2013; MacKerron & Mourato, 2013). Those behavioral changes by police officers and drivers likely manifest themselves by changes in the number of traffic stops and citations issued. For example, adverse weather could reduce the number of traffic stops because police officers prefer to remain warm and dry inside the police car rather than being wet and cold while conducting a stop. Police officers may also be more occupied with car accidents instead of pulling people over. Conversely, adverse weather conditions are expected to increase the number of traffic stops as a new infraction category, "driving too fast for conditions," leaving police officers relatively large room for discretion and the "opportunity" to pull over more drivers (Islam & Mannering, 2021). Motorists could also change their driving behavior during adverse weather. For instance, in rainy/snowy conditions, drivers may commit fewer infractions (e.g., drive slower and below the speed limit) or forego vehicle usage, which reduces the number of traffic stops. They could also experience frustration because of adverse weather or otherwise react to poor road conditions, increasing the likelihood of an infraction (Hamdar et al., 2016). In any case, the number of traffic stops would not serve as an indication of a change in behavior of police officers during rainy/snowy conditions because of the simultaneous change in driving behavior of road users as well.

Weather tends to have a greater impact on police officers, who must exit their vehicles, than on drivers, who are shielded from weather fluctuations, although drivers still react to changes in road conditions (e.g., driving slower) caused by adverse weather. Therefore, to address potential shifts in law enforcement practices caused by changes in police actions rather than driving behavior, we focus on analyzing the racial composition of stopped drivers instead of the total number of traffic stops and the probability of a citation being issued during a traffic stop.

We use two empirical approaches to analyze changes in the racial composition of traffic stops and their outcomes (i.e., warning vs. citation) during adverse weather. The first approach is based on the "Veil of Darkness" (VOD) hypothesis, as proposed by Grogger and Ridgeway (2006). The hypothesis asserts that officers are less able to discern a driver's race at night, suggesting that, if racial bias exists, Black drivers are less likely to be stopped after dark. Research testing the VOD hypothesis focuses on traffic stops occurring during certain hours of the day and times of the year to ensure consistent travel patterns (Grogger & Ridgeway, 2006; Pierson et al., 2020). Our approach restricts the sample similarly to tests of the VOD hypothesis. That is, we analyze traffic stops within ± 30 days of the shift to and from daylight savings time during March and November as well as the hours immediately before and after sunset. This approach ensures consistent driver composition while allowing for variations in driver visibility (Pierson et al., 2020). In addition, we include jurisdiction-specific fixed effects. The second approach uses the entire sample (i.e., all months and hours) and includes fixed effects related to the time of the day and the day of the week to adjust for variation in driving patterns associated with different hours of the day and days of the week. We conduct the estimation separately for each city and state agency in our data, which allows us to identify potential heterogeneity among the location of stops based on traffic laws, policing strategies, driver composition, the availability of public transportation, and other factors. The second approach also mitigates the impact of locations with a large number of observations in our models. This impact is undetected in our first approach based on the VOD hypothesis, since we pool the data and control for location characteristics using jurisdiction-fixed effects.

Changes in the racial distribution of stops could be the result of race-specific changes in driving behavior due to bad weather. As it is difficult to obtain data to be able to discern race-specific changes under adverse weather and hence, we follow the approach proposed in Grosjean et al. (2022). We examine fatal traffic accidents under varying weather and light conditions, acting as a proxy for race-specific changes in driving behavior. Results suggest that the probability of a Black driver being involved in a fatal crash is not affected by precipitation but is higher at night than during the day, potentially indicating that Black drivers are aware of their visibility during the day and drive more cautiously. The change in driving behavior of Black people during the night reduces the likelihood of observing racial bias in police stops when testing the VOD hypothesis (Kalinowski et al., 2021).

If race-specific changes in driving behavior under adverse weather are negligible, we expect the following relationship among adverse weather, administrative discretion, racial bias, and the racial distribution of traffic stops. If there is no racial bias in traffic stops, we do not expect the racial distribution of drivers during traffic stops to change under adverse weather conditions. Conversely, if racial bias is present, police officers might use their discretion in one of two ways. First, adverse weather is likely to (implicitly or explicitly) reduce racially motivated traffic stops, potentially decreasing the probability of a Black driver being pulled over relative to a White driver. Second, during adverse weather conditions, police officers might be more lenient toward White drivers and stop them less, thereby increasing the probability of a stopped motorist being Black. Note that in the first scenario, the racially motivated gap between White and Black drivers is reduced, whereas in the second scenario, the gap is increased. Our analysis cannot fully eliminate the influence of changes in driving behavior during adverse weather on the racial distribution of traffic stops. Thus, we interpret the findings of our analysis not as causal but a first important step in investigating the relationship among weather, administrative discretion, racial bias, and the racial distribution of traffic stops.

Coupling data from the Stanford Open Policing Project with hourly county-level precipitation and temperature data, we investigate traffic stops and citations in 37 city and 11 state police departments (Pierson et al., 2020). We find that precipitation and temperature influence the racial distribution of drivers during traffic stops. To illustrate the magnitude of those findings based on our models, we calculate predicted probabilities for precipitation ranging from no rain to 3 mm (mm) per 20-min interval and temperature ranging from −10°C to 30°C. Our results based on the data associated with the VOD hypothesis shows the probability of a stopped driver being Black varies by 9.2 (day) and 9.8 (night) percentage points for city agencies and by 17.7 (day) and 18.7 (night) percentage points for state agencies across the temperature and precipitation range. For cooler temperatures, the effects of rain are more pronounced for state than city agencies. At or below 10°C, the probability of a driver being Black always decreases for state agencies (−4.5 to −9.6% points during the day) whereas the change for city agencies is from 3.7 to −1.3% points. Although similar in range, there is a difference between city and state departments. That is, during heavy precipitation and very cold temperature, the probability of a stopped driver being Black drops to one-third of the value during no rain for state police. Precipitation leads to an increase in citations (as opposed to a warning) issued by state police but not city police, possibly indicating that police officers only conduct traffic stops for major infractions during adverse weather. Important interactions occur with precipitation at night when conducting a traffic stop is more dangerous due to reduced visibility.

Our analysis contributes three main findings to research on administrative discretion, variations in policing practices, and the measurement of racial discrimination during traffic stops. First, we conceptually demonstrate how administrative discretion can influence law enforcement practices during adverse weather conditions, both with and without the presence of racial bias, contributing to research evaluating discretion in policing (Beckett, 2016; Bronitt & Stenning, 2011; Mahoro, 2021). Our analysis indicates that adverse weather conditions likely influence how law enforcement officers use their discretion. We offer empirical evidence of these shifts, highlighting significant variations in using discretion across city and state police departments, especially in response to adverse weather. Second, our models suggest that tests of the VOD hypothesis, aimed at detecting racial discrimination, are sensitive to the specification used and the sample of jurisdictions examined. Finally, our work adds to the growing body of literature examining factors that affect differential interactions between police and citizens of various races, a topic of particular importance given the profound impact of violent police encounters on families and communities (Ba et al., 2021; Gerberg & Li, 2022; Hoekstra & Sloan, 2022; Oppel et al., 2022; Roh & Robinson, 2009; Rojek et al., 2012). Police misconduct leads to high costs for cities and states, who are legally liable for the actions of their law enforcement agencies (Alexander et al., 2022; Ouss & Rappaport, 2020; Rosenberg, 2019).

We provide the groundwork to test for administrative discretion and racial bias in traffic stops that scholars and practitioners can further expanded. Our study contributes to the discussion of policing and race, which is fueled by arguments over the prevalence of police using force and officer-involved shootings, with the latter being much more frequent in the U.S. than in other industrialized countries (Hirschfield, 2015). Given that many fatal shootings originate during a traffic stop, there is additional need to eliminate unnecessary police encounters, i.e., those based on racial bias.[1]

Data

This section outlines our data on traffic stops as well as weather and sunlight conditions. It also explains the subset used for the analysis based on the VOD hypothesis. A https://www.github.com/trafficstops/paperGitHub repository contains all data and code to replicate our analysis as well as a Supplemental Information and additional analysis providing data summaries.

Traffic stops

We use 2011–2018 data on traffic stops and citations from the Stanford Open Policing Project (Pierson et al., 2020).[2] We restrict the data in several ways for our analysis. First, we exclude jurisdictions with more than 50% missing values for the variables *date*, *time*, *race*, and (for state agencies) *county* from the analysis, as data availability could be driven by nonrandom factors. Second, given that we calculate the average temperature and precipitation within a county, we also exclude states in the western part of the U.S. due to large county sizes.[3] That is, temperature and precipitation may vary substantially across a large county at a given time leading to an inaccurate match between weather and traffic stops, which are at the county level. In total, we have 37 city and 11 state agencies in our analysis. Compared to Pierson et al. (2020), we exclude Pittsburgh (Pennsylvania) from the city analysis and add Mesa (Arizona), Grand Forks (North Dakota), and Owensboro (Kentucky). Our state analysis substantially differs from Pierson et al. (2020) as we exclude Arizona, Montana, and Washington, given large county sizes within those states, and remove California, Colorado, Illinois, Massachusetts, North Carolina, Rhode Island, and South Carolina because of missing data. Thus, our state analysis includes only 45% of state observations compared to Pierson et al. (2020).[4] To analyze the racial distribution of stopped drivers, we focus on Black and White drivers. As in Pierson et al. (2020), we exclude Hispanic drivers because the ethnicity is not always apparent from a distance—a condition forming the basis of the VOD hypothesis—even during daylight. To evaluate citations, we add Hispanic drivers to the sample because the ethnicity is identifiable (to the degree possible) if the police officer interacts with the driver face-to-face.

Weather and sunlight conditions

We use the North American Land Data Assimilation System (NLDAS) as a source of hourly temperature and precipitation data.[5] We aggregate this information to the mean air temperature and precipitation at the county level. There is usually little variability in temperature over the period of

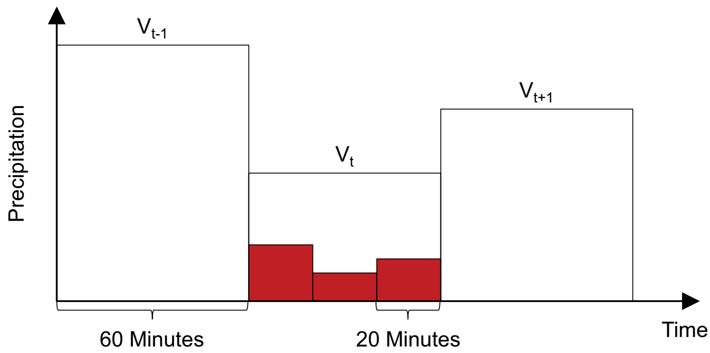

Figure 1. Illustration of the discrete 20-min interval disaggregation model (Ormsbee, 1989). In this example, the hourly rain data *V* is 2, 1, and 1.5 millimeters (mm) in $t-1$, t, and $t+1$, respectively. The discrete 20-minute interval disaggregation model leads to rainfall of 0.44, 0.22, and 0.34 in hour *t* which sums up to 1 mm.

1 hour and we assume that no matter when a traffic stop takes place, the temperature corresponds to the hourly NLDAS value.

The same assumption of little variability over the period of 1 hour is not valid for precipitation. For example, if a traffic stop occurs at 18:50, and it rains 10, 5, and 0 millimeters (mm) in the hours starting at 17:00, 18:00, and 19:00, respectively, then the precipitation during the traffic stop is probably closer to the 0 mm than 5 mm. Because a smaller temporal resolution than 1 hour is not available, we disaggregate the precipitation data using an approach from the hydrology literature, taking into account the precipitation in the hour preceding and following the traffic stop. We disaggregate precipitation over an hour into 20-min intervals as follows (Ormsbee, 1989):

$$V_t^1 = V_t \cdot \frac{V_{t-1}}{V_T} \tag{1}$$

$$V_t^2 = V_t \cdot \frac{V_t}{V_T} \tag{2}$$

$$V_t^3 = V_t \cdot \frac{V_{t+1}}{V_T} \tag{3}$$

where $V_T = V_{t-1} + V_t + V_{t+1}$. Figure 1 provides an illustration of the precipitation data disaggregation using Equations (1)–(3). We match the 20-min rainfall interval with the time of the traffic stop in our statistical model. Figure 2 illustrates our approach for city and state data.

Our main results include precipitation in all its forms (e.g., rain and snow) and the supplemental information contains the results for rain only (defined as precipitation given an air temperature of over 5°C). Limiting our analysis to rain does not lead to different findings. The results are also robust with respect to the disaggregation model and time interval (e.g., 10- or 15-min interval) chosen, as shown in the supplemental information.

We use the city locations and county centroids to calculate the sunlight conditions (i.e., day vs. night) and sun positions for our analysis (National Atlas of the United States, 2014, USDA, 2017). Note that we exclude the traffic stops that occurred during civil twilight (i.e., the sun being between 0 and 6 degrees below the horizon) because of ambiguous day/night lighting conditions.

Veil-of-darkness sample subset

To evaluate how the inclusion of weather affects previous tests of the VOD hypothesis, we follow Grogger and Ridgeway (2006) and Pierson et al. (2020) and take a subset of our sample to reduce

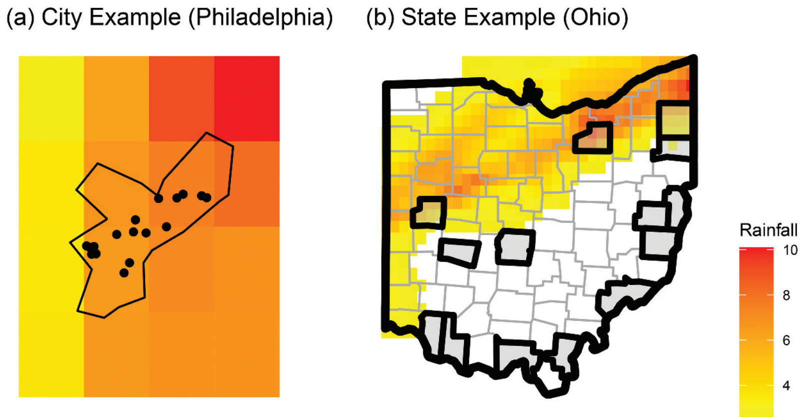

Figure 2. Illustration of the spatial approach for city and state police agencies with respect to weather data. The example uses Philadelphia and Ohio. Panel (a) depicts traffic stops (black dots) and precipitation (in millimeters) on February 25, 2017, between 17:00 and 18:00 in Philadelphia County. Temperature and precipitation data are county averages of gridded data from the North American Land Data Assimilation System (NLDAS). Panel (b) depicts counties with traffic stops on November 15, 2011, between 16:00 and 17:00 in Ohio. All precipitation data is disaggregated into 20-minute intervals to derive the likely distribution over an hour taking into account precipitation of the previous and next hour (Ormsbee, 1989).

potential intra-year and intra-day seasonality. That is, we keep only traffic stops that occurred $\pm$ 30 days around the change in daylight savings time (DST) during March and November. In addition, for each city, county, and year, we calculate the earliest and latest time of sunset around $\pm$30 days of DST change. We only include traffic stops falling within that period in our approach based on the VOD hypothesis (Grogger & Ridgeway, 2006; Pierson et al., 2020). For example, if the earliest sunset for a jurisdiction is 17:00 in the winter and 20:00 in the summer, then we only include the traffic stops occurring between 17:00 and 20:00 in the sample. Limiting the observations to the days around the switch to and from DST as well as the evening hours reduces as much as possible issues regarding seasonal (intra-day and -year) and racial and ethnic differences in driving patters due to variation in traffic volume, exposure to police officers, commuting times, etc (Pierson et al., 2020).

Methods

Below, we describe the statistical model used to analyze weather-related changes in the racial distribution of stopped drivers and citation issuance. In addition, we address issues surrounding race-specific driving behavior at night and under adverse weather conditions using data on fatal traffic accidents similar to the analysis by Grosjean et al. (2022).

Racial composition of traffic stops and citation issuance

To assess the effect of adverse weather on the racial distribution of drivers during traffic stops and citations, we leverage variations in precipitation and temperature over time and space. We run four sets of logit models, estimating the probability of a stopped driver being Black (B) or a citation being issued (C) using either the data based on the VOD hypothesis or the entire data set. We focus on three key variables associated with the conditions during the traffic stop: *Night* (dummy variable that equals 1 after sunset and is 0 otherwise), precipitation (*Precip*), and temperature (*Temp*). We run several specifications based on these three variables. Some models include interactions between precipitation and temperature, as the cost of conducting a traffic stop under two adverse weather conditions may not be the sum of both individual effects. We also estimate equations with interactions between precipitation and night, given that both conditions decrease the visibility of drivers and could reinforce each other.[6] We specify our logit models using the subset based on the VOD hypothesis as follows:

$$\ln\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \lambda_y + \lambda_t + \lambda_w + \lambda_j + \beta_1 \times Nonwhite_i \times I_C + \beta_2 \times DST + \beta_3 \times Night_i + \beta_4 \times Precip_i + \beta_5 \times Temp_i + \beta_6 \times Precip_i \times Temp_i + \beta_7 \times Precip_i \times Night_i \quad (4)$$

We specify our logit models using the entire data set as follows:

$$\ln\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \lambda_y + \lambda_t + \lambda_w + \lambda_m + \beta_1 \times Nonwhite_i \times I_C + \beta_2 \times Night_i + \beta_3 \times Precip_i + \beta_4 \times Temp_i + \beta_5 \times Precip_i \times Temp_i + \beta_6 \times Precip_i \times Night_i \quad (5)$$

Besides the already discussed variables and the constant term β_0, Equations (4) and (5) also incorporate the following terms: The variables λ_y, λ_t, and λ_w denote time-fixed effects for year, time of day, and day of week for all jurisdictions. The variables λ_j and λ_m designate jurisdiction and month fixed effects, respectively.[7] The dummy variable *DST* indicates the change to and from daylight savings times in the spring ($DST = 1$) and fall ($DST = 0$). Our model differs from Pierson et al. (2020) in that we use dummy variables for the time of day as opposed to a natural spline. The reason for this approach is to ensure consistency between our approach based on the VOD hypothesis, covering only evening hours, and the full sample, requiring controls for the different hours of the day. The indicator function I_C is equal to 1 if we estimate the citation model since that model includes the race/ethnicity of the stopped driver. We do not include the variable *Nonwhite* in the models assessing the probability of a stopped driver being Black since the dependent variable is binary (i.e., Black or White). The coefficients of interest are attached to the variables *Night*, *Precipitation*, and *Temperature* as well as the interaction terms associated with those variables. Note that we expect negative coefficients if adverse weather were to decrease discrimination against Black drivers. Conversely, we anticipate positive coefficients if adverse weather makes it less likely that a White driver is stopped.

Compared to prior research, using similar data, our models differ in two points. First, we separately estimate models for traffic stops by city and state police departments, as prior research reveals differences in their work routines and their ability to identify a driver's race, given speed differences on highways and city roads (Warren et al., 2006). This strategy also avoids adding a significant number of interaction terms to the model (e.g., city/state dummy with temperature and precipitation and their interactions). Second, we include fixed effects for year, time of day, and day of the week in our equation to control for changes in the racial composition of traffic stops that are not controlled for by the independent variables included in our model. Although we use the term *Night*, we point out that we refer to the hours between the earliest sunset in winter and the latest sunset in summer in the model based on the VOD hypothesis as described in the section *Veil-of-Darkness Sample Subset*.

Testing for race-specific changes in driving behavior

An important aspect of our study is the influence of the race-specific (1) composition of those choosing to drive at a particular time and (2) differences in driving behavior given changes in weather. We use data to test for the relationship between race and fatal car accidents under varying weather and visibility conditions to provide evidence in favor of those changes being potentially small (Grosjean et al., 2022). As the literature on weather and crime postulates that individuals must be directly exposed to rain or heat to change their behavior (see supplemental information 1.3), we expect that weather mainly triggers behavioral changes in police officers, who have to leave their cars to conduct traffic stops, but not in drivers, who are more protected from rain and cold/heat.

Since a conceptual argument cannot fully rule out variation in driving behavior, we use data from the Fatality Analysis Reporting System (FARS) maintained by the U.S. Department of Transportation.[8] For the counties, days, and years used in our analysis, we run logistic regression models with the dependent variable being 1 if at least one Black driver was involved in a fatal car

Table 1. Logit regression results with the dependent variable *Black*, meaning at least one of the drivers involved in a fatal car accident is Black.

	Dependent variable: Black	
	City	State
Precipitation	−0.062	−0.066
	(0.159)	(0.088)
Year	0.059***	0.069***
	(0.017)	(0.009)
Daylight	0.058	−0.109**
	(0.084)	(0.047)
Constant	−122.282***	−141.552***
	(33.811)	(19.030)
Observations	8,131	26,893

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

accident. FARS does not include data on responsibility or fault of drivers. The explanatory variables are year and county fixed effects as well as *Precipitation*, which indicates the presence of precipitation (or lack thereof) during time of accident. We also add *Daylight* to the equation to control for visibility and to test the assumption of unchanged driving behavior for Black and White motorists during day and night (i.e., light condition during the accident).

We find that precipitation has no statistically significant impact on the probability of a Black driver being involved in a car accident (Table 1). This test is not sufficient to show a lack of behavioral responses to rain for three reasons. First, the outcome is extreme (i.e., fatal car crashes) and would not capture behavioral changes that do not affect this probability. Second, selection into driving in the rain and/or at night alters the risk distribution of drivers. Lastly, both factors may vary by race. This finding suggests that driving behavior during precipitation does not vary based on race. Table 1 also shows that Black drivers are more likely involved in a car accident during night, potentially indicating differences in driving behavior based on light conditions. This finding adds to evidence provided by Kalinowski et al. (2021), who argue that tests of the VOD hypothesis likely underestimate racial bias in traffic stops, as non-White drivers are aware of being less visible during nighttime. In addition, police officers may tend to initiate a traffic stop only for more serious infractions during bad weather. However, weather also influences driving behavior of all road users and the number of accidents (Bergel-Hayat et al., 2013; Sutela & Aaltonen, 2021).

Results

The results section is divided into three parts. The first part presents models investigating the racial distribution of stopped drivers, and the second part reports findings for specifications estimating the probability of receiving a citation during a traffic stop. Both sections are based on the data subset associated with the VOD hypothesis, which includes stops and citations ±30 days around the change in daylight savings time and the hours before and after sunset (see section *Veil-of-Darkness Sample Subset*). For the analysis in both models, we differentiate between city and state police agencies and employ jurisdiction-fixed effects. The third part of this section discusses the coefficients for models incorporating all months and hours available in our data set. We estimate regressions separately for each jurisdiction to reduce the influence of locations with large numbers of observations and to investigate potential heterogeneity in effect sizes among jurisdictions (see section *Traffic Stops*). Due to the extensive number of regression models and calculations for all of our specification, we present only a small subset of coefficients. Interested readers may want to consult the supplemental information for additional findings.

For the first two sections, using the subset associated with the VOD hypothesis, we report raw coefficients in tables and predicted and marginal probabilities in figures. We calculate these probabilities because interpreting interactions, including continuous variables, requires applying actual values to each variable. Calculations are based on Equations (4) and (5) and utilize precipitation values of 0, 1, 2, and 3 mm per 20-minute intervals and *Temperature* values between −10°C to 30°C in 10°C steps.[9] All other variables in the equations are held constant at their mean values. Coefficient sizes are taken from models including all interactions terms (see columns C7 and S7) in Tables 2 and 3.

VOD analysis: Racial distribution of stopped drivers

Table 2 presents the results for models using the race of a driver during a traffic stop as dependent variable. We expect the estimator associated with the VOD hypothesis to be negative and statistically significant and that adverse weather will change the probability of a Black motorist being pulled over. Focusing on the city models (Table 2), we find that the coefficients of the *Night* variable are not statistically significant. For the state models, the coefficients associated with *Night* are positive and statistically significant—contradicting the VOD hypothesis—when temperature is included.

Figure 3 displays predicted and marginal probabilities. During nighttime, weather does not influence the likelihood of a Black driver being pulled over by a city police department. However, during the daytime, temperature affects traffic stops. For instance, an increase in temperature from 20°C to 30°C at a precipitation of 3 mm increase the probability of a Black motorist being stopped by 2.2% points, relative to a White motorist (see supplemental information for calculation of all probabilities). The marginal probability of a driver being Black during the day for city departments is positive (statistically different from zero at the 5% level) for warmer temperatures. In contrast, the impact of weather on stops by state police agencies is more pronounced. We find that at night and at

Table 2. Logit regression results for the city and state models on the probability of a driver being Black given a traffic stop and the explanatory variables based on versions of Equation (4). The fixed effects coefficients (i.e., year, jurisdiction, time of day, day of week) and the coefficient for daylight savings time are omitted in this table but can be replicated given the supplemental information associated with this manuscript.

	Dependent variable: Black						
City	(C1)	(C2)	(C3)	(C4)	(C5)	(C6)	(C7)
Night	−0.005	−0.005	−0.002	−0.011	−0.011	−0.011	−0.008
	(0.009)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.010)
Precip		0.032*	0.080***	0.033*		−1.528*	−0.902
		(0.018)	(0.024)	(0.018)		(0.813)	(0.846)
Precip × Night			−0.123***				−0.111***
			(0.037)				(0.039)
Temp				−0.001	−0.001	−0.001*	−0.001
				(0.001)	(0.001)	(0.001)	(0.001)
Precip × Temp						0.005*	0.003
						(0.003)	(0.003)
Constant	0.103	0.102	0.102	0.367	0.354	0.392	0.367
	(0.192)	(0.192)	(0.192)	(0.254)	(0.254)	(0.254)	(0.254)
Observations	458,976	458,976	458,976	458,976	458,976	458,976	458,976
State	(S1)	(S2)	(S3)	(S4)	(S5)	(S6)	(S7)
Night	0.002	0.002	0.002	0.041***	0.041***	0.041***	0.041***
	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)
Precip		0.002	0.005	−0.015		−3.873***	−3.981***
		(0.026)	(0.034)	(0.026)		(1.058)	(1.088)
Precip × Night			−0.008				0.023
			(0.052)				(0.053)
Temp				0.006***	0.006***	0.006***	0.006***
				(0.0005)	(0.0005)	(0.0005)	(0.0005)
Precip × Temp						0.013***	0.014***
						(0.004)	(0.004)
Constant	−4.467***	−4.467***	−4.467***	−6.071***	−6.066***	−6.050***	−6.048***
	(0.710)	(0.710)	(0.710)	(0.723)	(0.723)	(0.723)	(0.723)
Observations	981,192	981,192	981,192	981,192	981,192	981,192	981,192

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

Table 3. Logit regression results for the city and state models on the probability of a police officer issuing a citation during a traffic stop based on versions of Equation (4). All specifications control for the race of drivers. The jurisdiction-fixed effects, the period of the daylight savings time, and the coefficients for the year fixed effects are omitted in the results reporting.

	Dependent variable: citation						
City	(C1)	(C2)	(C3)	(C4)	(C5)	(C6)	(C7)
Nonwhite	−0.130***	−0.130***	−0.130***	−0.130***	−0.130***	−0.130***	−0.130***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Night	−0.219***	−0.219***	−0.219***	−0.221***	−0.221***	−0.221***	−0.221***
	(0.018)	(0.018)	(0.018)	(0.020)	(0.020)	(0.020)	(0.020)
Precip		−0.033	−0.024	−0.033		−0.221	−0.142
		(0.043)	(0.063)	(0.043)		(2.064)	(2.108)
Precip × Night			−0.018				−0.016
			(0.086)				(0.088)
Temp				−0.0004	−0.0004	−0.0004	−0.0004
				(0.001)	(0.001)	(0.001)	(0.001)
Precip × Temp						0.001	0.0004
						(0.007)	(0.007)
Constant	−0.196	−0.196	−0.196	−0.090	−0.080	−0.088	−0.091
	(0.168)	(0.168)	(0.168)	(0.389)	(0.389)	(0.389)	(0.390)
Observations	101,427	101,427	101,427	101,427	101,427	101,427	101,427
State	(S1)	(S2)	(S3)	(S4)	(S5)		
Nonwhite	0.389***	0.389***	0.389***	0.390***	0.390***	0.390***	0.390***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Night	−0.381***	−0.381***	−0.383***	−0.385***	−0.385***	−0.385***	−0.388***
	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)
Precip		0.419***	0.268***	0.421***		1.732	0.589
		(0.035)	(0.047)	(0.035)		(1.320)	(1.345)
Precip × Night			0.314***				0.312***
			(0.071)				(0.072)
Temp				−0.001	−0.0005	−0.001	−0.001
				(0.0005)	(0.0005)	(0.0005)	(0.0005)
Precip × Temp						−0.004	−0.001
						(0.005)	(0.005)
Constant	1.103	1.102	1.103	1.279	1.238	1.274	1.285
	(1.031)	(1.031)	(1.031)	(1.039)	(1.039)	(1.039)	(1.039)
Observations	571,232	571,232	571,232	571,232	571,232	571,232	571,232

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

a precipitation of 3 mm, a decrease of up to 6.9% points (for a temperature decrease from 30°C to 20°C). If precipitation increases from 1 to 3 mm at a temperature of −10°C during nighttime, the probability of a pulled-over driver being Black decreases by 5.3% points. The marginal probabilities at cold temperatures (below freezing) are up to 5.1% points for state police independent of day vs. night. This finding is in line with our expectations that the probability of a pulled-over driver being Black decreases significantly during adverse weather.

VOD analysis: Probability of citation issuance

For some cities and states in the sample, we have information on whether police officers issued a citation during the traffic stop.[10] The dependent variable is *Citation* and we add Hispanics to the sample. As aforementioned, we expect that police officers become more selective in traffic stop initiation and are more likely to pull over drivers for serious infractions (see Table 3 and Figure 4). The coefficients in Table 3 suggest that being *Nonwhite* decreases the probability of receiving a citation for city departments but increases for state agencies. The magnitude of the coefficients as well as the significance levels are similar across the model.

Figure 4 shows predicted and marginal probabilities. There is no evidence that weather influences citations from city police departments (Panels [a] and [c], Figure 4). All marginal probabilities are not

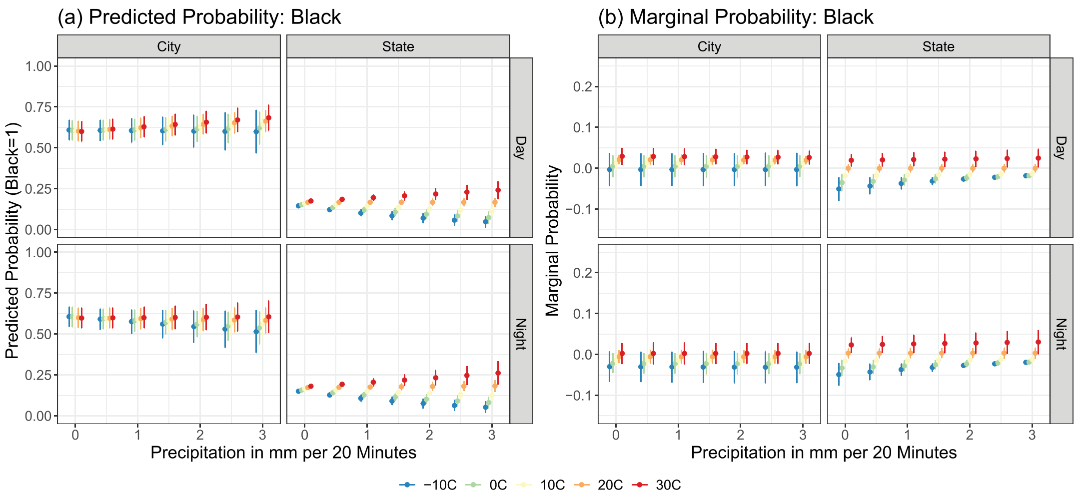

Figure 3. Predicted and marginal probabilities of a pulled-over driver being Black as a function of precipitation, temperature, state vs. city, and day vs. night. The temperature range from -10° to 30° is measured in Celsius. All other variables are held constant. The bars indicate the 95% confidence interval.

statistically significant. The results are very different for state police departments. The likelihood of receiving a ticket increases with precipitation regardless of temperatures, race, and ethnicity. The marginal probabilities are all very different from zero (at the 5% level). For example, a change in precipitation from 1 mm to 3 mm is associated with an increase of 11.9 and 12.6% points in receiving a citation for nonwhite and White drivers, respectively, holding temperature constant at 30°C during the day.

Our approaches are consistent with the empirical models used by Pierson et al. (2020). That is, we use jurisdiction-fixed effects to estimate the effect of the VOD hypothesis and weather on the probability of a stopped driver being Black and receiving a citation. The next section presents the results based on all observations. We will demonstrate that jurisdictions with a substantial number of observations, such as the Texas State Police in the case of citations, can significantly influence the outcomes.

Jurisdiction-specific analysis: Marginal probabilities

To assess the heterogeneity among locations, we use Equation 5 and estimate separate models for each jurisdiction, incorporating all stop times and days. This approach mitigates the influence of jurisdictions with large numbers of observations and allows us to reveal heterogeneity among locations. The regression tables and results for the 48 jurisdictions are available in the supplemental information.

We first normalize the precipitation and temperature in Figures 5 and 6 as follows. To obtain representative precipitation values by jurisdiction, we first disregard values below 0.1 mm to eliminate observations with no or too little (i.e., barely noticeable) precipitation. Next, we eliminate outliers and calculate the precipitation values for the three cutoff points associated with quartiles. This procedure allows us to compare the marginal probabilities of all jurisdictions in the same figure. We calculate the cutoff points for quartiles 1–3 since our temperature measure is in Kelvin, which does not include zero values.[11] Figures 5 and 6 depict the marginal probabilities for precipitation at the third quartile cutoff point. The supplemental information provides results for all other precipitation levels.

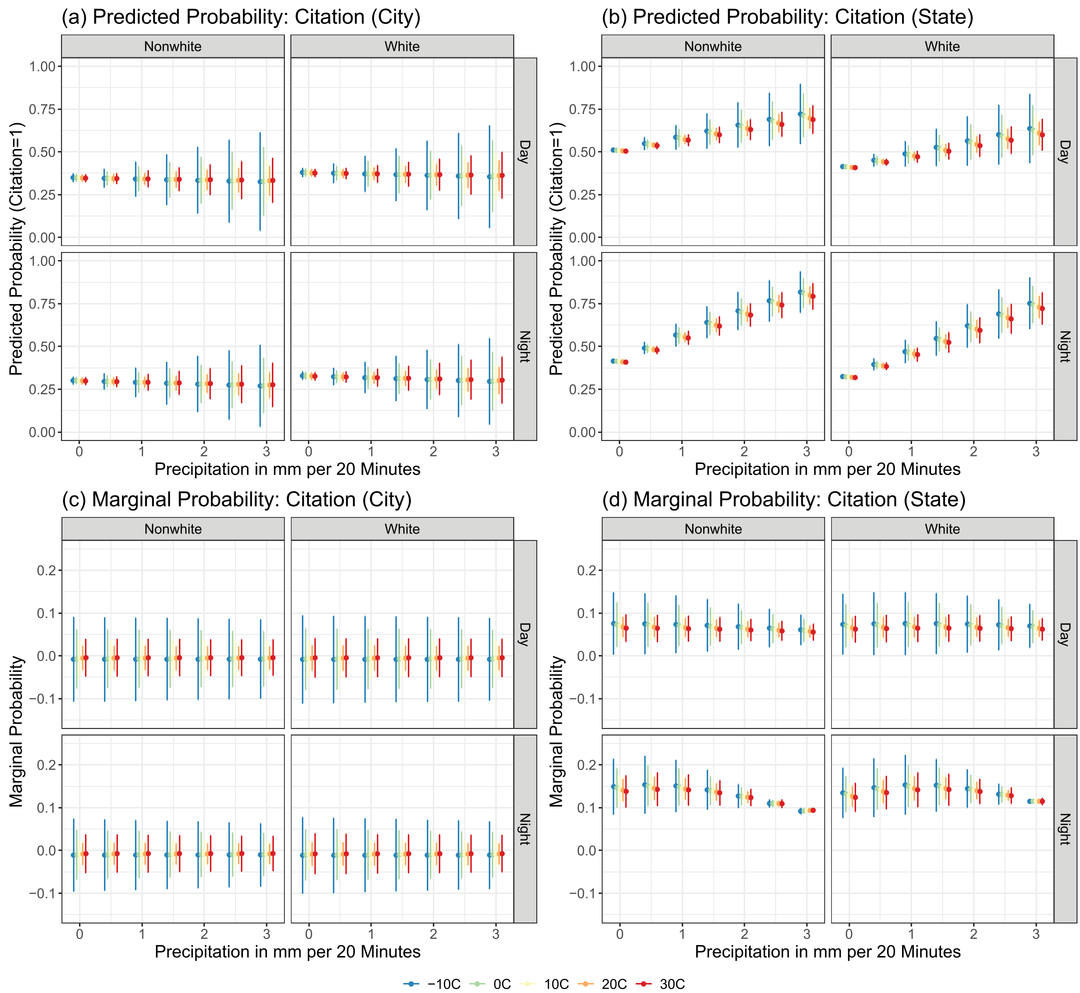

Figure 4. Predicted and marginal probabilities of city police officers issuing a citation as a function of precipitation, temperature, nonwhite drivers, and day vs. night. The temperature range from -10° to 30° is measured in celsius. All other variables are taken at their mean. The bars indicate the 95% confidence interval.

Jurisdictions for which the marginal probability of a stopped driver being Black is positive and different from zero at the 5% level are Connecticut State Police, Louisville, Nashville, Oklahoma City, Oakland (only for relatively cold temperature at the first quartile) Raleigh, and Texas State Police. Mesa (Arizona) and New York State Police have negative marginal probabilities in regard to rain (Figure 5). If we consider temperature being relatively cold, i.e., at the first quartile, only Oakland is added to the previous list of positive marginal probabilities. There are substantially more jurisdictions that have a negative marginal impact different from zero when it is cooler: Charlotte, Los Angeles, Madison, Michigan State Police, New York State Police, and New Orleans.

There are large differences in the number of observations by jurisdiction. The cities with the largest number (above 1 million) of traffic stops in our sample are Los Angeles, Nashville, and Philadelphia. For states, the highest number of observations are for Florida, New York, Ohio, Tennessee, and Texas.[12] Recall that the results from the data subset based on the VOD hypothesis indicate an increase in the probability of receiving a citation with precipitation (Figure 4).

The probability of receiving a citation can increase by more than 20% points during cold temperatures for Texas State Police (Figure 6). Note that Texas State Police has over 13.6 million observations

Figure 5. Point estimate and 95% confidence interval of the marginal probability of a stopped driver being Black with respect to precipitation levels at the third quartile cutoff point.

in our model, leading to very small confidence intervals. Other police departments that have positive marginal probabilities are Madison Police Department (Wisconsin) and Michigan State Police. Numerous city and state departments exhibit negative marginal probabilities with an increase in citations (Figure 6). Our results suggest that there is substantial heterogeneity among jurisdictions and how adverse weather impacts administrative discretion.

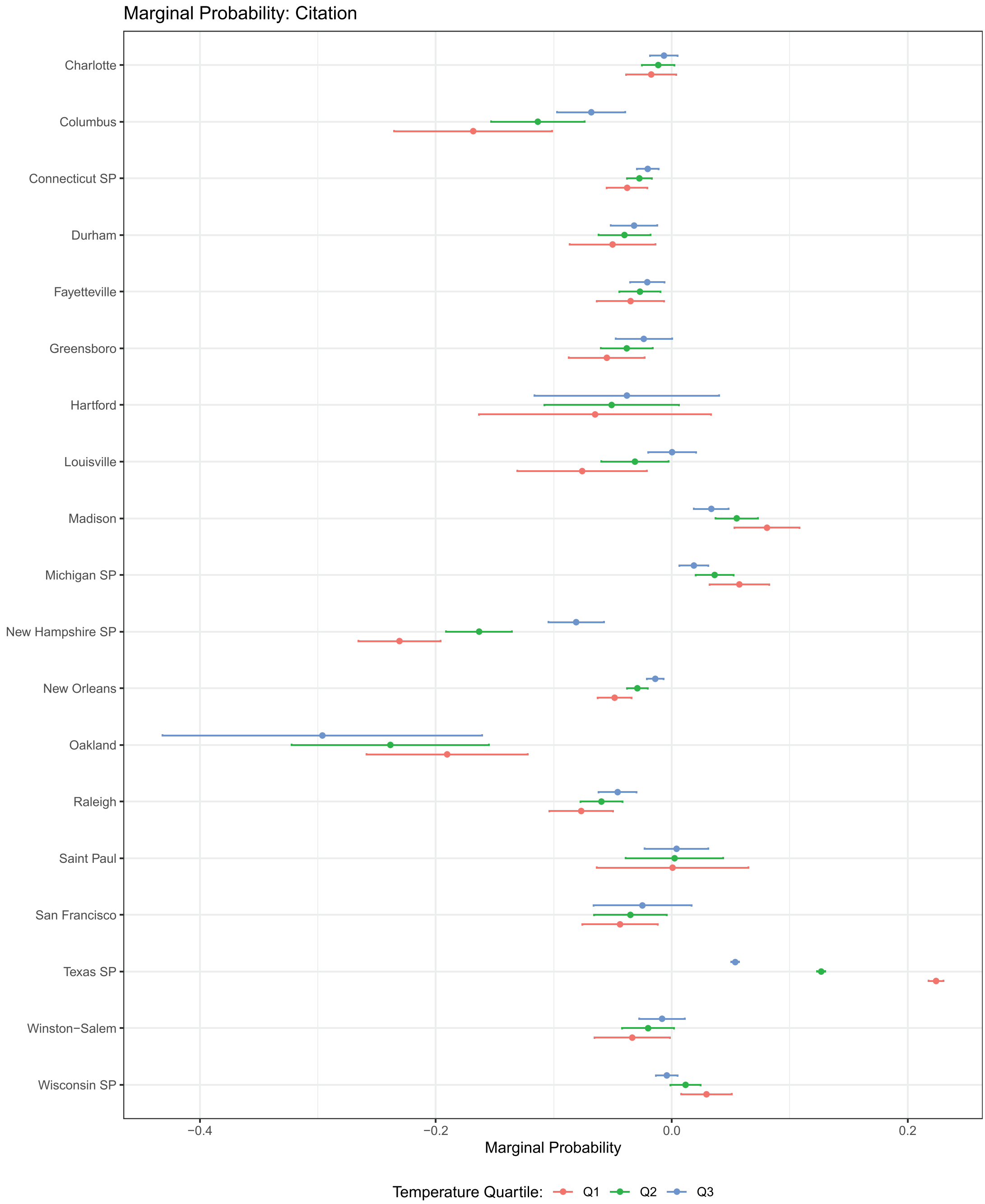

Figure 6. Point estimate and 95% confidence interval of the marginal probability of a citation issuance with respect to precipitation levels at the third quartile cutoff point.

Discussion and conclusion

Traffic stops are the most common form of citizen–government interactions. Police officers exercise considerable discretion over traffic law enforcement, and this discretion has been criticized for racial disparities in stops and citations. In this study, we leverage variation in weather to examine changes in the racial distribution of drivers being stopped and cited. We hypothesize that adverse weather increases the cost of conducting a traffic stop and writing a ticket for police officers, while drivers are protected in their cars. To provide evidence that precipitation and temperature do not influence the driving behavior differently for Black and White drivers, we analyze data on fatal car accidents during rain and snow, and do not find a statistically significant difference between Black and White drivers. Nonetheless, we interpret the results of our analysis as exploratory and not causal, providing a first step into understanding the relationship among police discretion, weather, and the racial distribution of traffic stops and citations.

The findings of our analysis reveal that tests of the VOD hypothesis are sensitive to changes in sample and model specifications. None of our models detect the hypothesized statistically significant negative relationship between non-visibility and traffic stops. These results are consistent with studies emphasizing that drivers are aware of their visibility (Kalinowski et al., 2021) and that policing shows significant differences between jurisdictions (see supplemental information for additional literature).

However, for the specification using the data subset associated with the VOD hypothesis, we find that the racial distribution of stopped drivers changes with precipitation and temperature. The probability of being stopped by a city police department increases for Black drivers at higher temperatures. State police departments are less likely to stop Black drivers when it is cold and when precipitation is heavy. Weather is not associated with citations issued by city police departments. In contrast, state police departments are more likely to issue tickets to both nonwhite and White drivers when precipitation increases.

These results hint at the potential for racial bias in policing, likely driven by the increased costs of traffic stops during adverse weather. More specifically, in city police departments, these costs are mitigated by being more lenient with infractions by White compared to Black motorists, increasing the probability of a Black driver being pulled over. For state police departments, it is probable that during frost and snow, existing prejudices against Black motorists are outweighed by the discomfort of getting cold and wet, decreasing the probability of a Black driver being pulled over relative to a White driver. State police officers issue tickets at a higher rate during rain for drivers of all races, suggesting that the costs of conducting a stop and writing a citation are offset by pulling over only those drivers who have committed an infraction.

Using all available observations and separating the estimation out by jurisdiction reveals substantial heterogeneity among jurisdictions and the issue of jurisdictions with a large number of observations influencing the results. Weather does not affect the racial distribution of drivers and the probability of a citation being issued in case of a small number of jurisdictions. This finding suggests that administrative discretion is likely influenced by weather in one way or the other.

Our results, describing differences in the use of discretion between city and state police, are corroborated by studies contrasting law enforcement in both jurisdictions. State officers do not routinely patrol neighborhoods or answer routine calls for service. Their deployment may also vary from city police departments, including more locations on highways where high speed does not allow for racial profiling. As a consequence, racial distributions in stops and citations could differ.

At this point, it is difficult to say if there are any other factors that drive variation in the use of discretion between police departments. Additional studies exploring the actual behavior of police officers, but also drivers of different races, could shed more light on these questions. Analyzing more comprehensive data sets including all state police departments or information about police missions, culture, and member characteristics are other possibilities to further illuminate the issues raised in our study.

The purpose of our study is to highlight that the current practice of police officers pulling drivers over at their discretion leads to a change in the racial composition of drivers under different weather conditions. Future research should aim at explicitly assessing the origins of this change in composition. It is possible that drivers adjust their driving behavior to changes in weather based on race similar to what is potentially observed at night. However, our initial analysis does not provide evidence for that change occurring. The discussion of policing and race in the U.S. is fueled by arguments over the prevalence of police use of force and officer-involved shootings, with the latter being much more frequent in the U.S. than in other industrialized countries. Given that many fatal shootings of residents and police officers find their origin during a traffic stop, there is the additional need to eliminate unnecessary encounters, i.e., those based on racial bias.

Notes

1. A search for the terms *traffic stop* and/or *pull over* in the incident description of data from Fatal Encounters indicates 1,649 entries where people were killed with interactions with the police.
2. The data is available at The Stanford Open Policing Project.
3. The total number of jurisdictions available from The Stanford Open Policing Project is 88 of which 40 are dropped based on our data requirements.
4. The traffic stop data is taken at face value despite the possibility that some traffic stops may have been inaccurately included by agencies (Nierenberg, 2023; Procell et al., 2023).
5. The NLDAS data at a resolution of 0.125×0.125 is available after registering at https://ldas.gsfc.nasa.gov/nldasNASALDAS.
6. We also ran models with an interaction between *Night* and *Temperature*. None of these specifications yield statistically significant coefficients on the interaction term, and hence we exclude them from our results and discussion.
7. Jurisdictions are cities for stops by municipal police departments and counties for stops by state police departments.
8. See US DOT NHTSA Fatality Analysis Reporting System for data availability.
9. Based on American Meteorological Society and adjustments for rain measures of 20-minute intervals, one can differentiate between light (under 0.87 mm), moderate (between 0.87 and 2.54 mm), and heavy rain (above 2.54 mm).
10. See supplemental information for a list of cities and states.
11. For the estimation of the models, all temperature values are measured in Kelvin, which excludes zero.
12. The exact number for those jurisdictions listed as well as for all others can be found in the supplemental information.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

All the data and code for replication is available at https://www.github.com/trafficstops/paper.

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