

Measuring discrimination using natural experiments *

Nikhil Rao[†]

James Reeves[‡]

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Abstract

Disparities in high-stakes decision-making is common, but difficult to interpret as discrimination if there are group differences in unobservable factors relevant to the decisions. We show how to use a natural experiment to measure discrimination between individuals with identical potential outcomes or treatment effects. We restrict the relationship between selection into the treatment decision and average potential outcomes, using developments in the marginal treatment effects literature. This approach does not require randomly assigned decision-makers, which is a key requirement for existing approaches that estimate discrimination accounting for unobservable differences. We use our approach to study discrimination in two settings where decision-makers are not randomly assigned. We study racial discrimination in misdemeanor prosecution using a difference-in-difference (DiD) strategy generated by a budget cut that reduced prosecution rates in King County, Washington. Adjusting for racial differences in potential re-offence outcomes, white defendants were more likely to be prosecuted than minority defendants after the budget cut. This gap is concentrated among potentially weak cases, and evidence suggests that prosecutors were offsetting pre-prosecution disparities. We also study socio-economic discrimination in student grade promotion in Michigan Public Schools and illustrate the advantages and disadvantages of implementing our approach with a regression discontinuity design. Economically disadvantaged students are less likely to be promoted than non-disadvantaged students even after accounting for differences in potential academic success.

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[†]University of Michigan: nikhrao@umich.edu

[‡]University of Michigan: jmreeves@umich.edu

1 Introduction

There are concerns of discrimination based on group membership in high-stakes decisions made in a wide array of contexts, e.g., in education, employment, health and in the criminal legal system. However, measuring discrimination accurately is often challenging due to unobservable group differences (Becker, 1957; Aigner and Cain, 1977; Charles and Guryan, 2011).¹ The ideal measure of discrimination is one that compares individuals who are from two different groups, but are otherwise similar in terms of the relevant unobservable factors. In the canonical example of hiring discrimination, this involves measuring the hiring gap between people belonging to two different groups, but who would be equally productive if hired to the job. Since productivity is only observable upon hiring, measuring such a gap in practice is challenging.

Prior work estimates discrimination, adjusted for unobservable group differences, using an extrapolation-based approach that requires randomly assigned decision makers (Arnold, Dobbie, and Hull, 2022).² However, there are many contexts where quantifying discrimination is policy-relevant, groups may be unobservably different, but decision-makers are not randomly assigned.³ For example, measuring socio-economic discrimination in education decisions is difficult since teachers are rarely randomly assigned to students and student ability may vary by socio-economic status.

In this paper, we use a natural experiment to measure discrimination in a treatment decision (e.g., being hired) when the groups to be compared are unobservably different and decision-makers are not randomly assigned. We map common forms of quasi-experimental variation that shift the likelihood of treatment, e.g., regression discontinuity or difference-in-difference, to an instrumental variables (IV) framework (Angrist, Imbens, and Rubin, 1996). Using the IV framework, we first estimate how potential outcomes under each treatment state vary with the likelihood of receiving treatment within each group (e.g., race) (Imbens and Rubin, 1997). Then, within each group, we extrapolate this estimated relationship using either the direction of the relationship or a functional form restriction to estimate how the distribution of potential outcomes under each treatment state varies by group (Brinch, Mogstad, and Wiswall, 2017; Mogstad, Santos, and Torgovitsky, 2018; Kowalski, 2023a).

If the distribution of potential outcomes varies by group, we rescale observed prosecution rates so that individuals of each group are comparable in terms of unobserved potential outcomes, following Arnold, Dobbie, and Hull (2022). In this way, we use a natural experiment, rather than randomly assigned decision-makers, to estimate average discrimination, accounting for group differences in unobservable potential outcomes.

We study discrimination, using our approach, in two settings where decision-makers are not

¹Throughout this paper, we are agnostic on the source of any such differences. These might be the function of multiple sources of discrimination prior to the decision of interest or ‘systemic discrimination’ (Bohren, Hull, and Imas, 2022).

²While outcome tests can detect bias in the treatment of individuals at the margin of treatment (Becker, 1957; Anwar and Fang, 2006; Arnold, Dobbie, and Yang, 2018), they do not capture statistical discrimination (Hull, 2021) and do not quantify the magnitude of discrimination conditional on unobservable differences.

³When group differences are minimal, measuring discrimination does not require these adjustments (Goncalves and Mello, 2021; Harrington and Shaffer, 2023; Tuttle, 2023).

randomly assigned. Our primary application studies racial discrimination in misdemeanor prosecution using difference-in-difference (DiD) design generated by a budget cut that reduced prosecution rates in King County, Washington. Unlike regression discontinuity (RD) designs that have a familiar mapping to IV frameworks, it is more challenging to map DiD approaches and IV. This is because time trends in potential outcomes can act as confounders (De Chaisemartin and D’Haultfoeuille, 2018). We overcome this by using trends in potential outcomes in the Washington counties that did not experience a budget cut to purge trends in potential outcomes in King County, assuming i) that time does not influence treatment status and ii) a form of a parallel trends in potential outcomes. We use this to non-parametrically estimate average potential outcomes for each racial group in King County, which allows us to understand whether the distribution of potential outcomes in King County differs by race. Adjusting for these differences, we measure racial discrimination in prosecution conditional on potential outcomes, both before and after the King County budget cut.

We also measure discrimination by socio-economic status (SES) in the decision to promote Michigan 3rd graders to the 4th grade, using a test score RD design used in prior work studying the impacts of student grade promotion (Westall et al., 2022a,b; Berne et al., 2023). We use the RD, which induces an increase in the probability of promotion, to estimate and adjust for SES differences in the likelihood of succeeding in 4th grade. While these estimates do not require the auxiliary DiD assumptions, the “local” nature of RD estimates makes the resulting discrimination estimates valid only at the RD cut-off without additional assumptions (Angrist and Rokkanen, 2015; Cattaneo et al., 2021). We discuss the implications of our findings for discrimination elsewhere in the test score distribution.

To outline the intuition of our approach, consider a potential outcomes framing of prosecution (Rubin, 1974). Define treatment as $D_i = 1$ if an individual is prosecuted, and $D_i = 0$ if dismissed. For simplicity, let the potential outcomes associated with each treatment state be binary.⁴ The treated potential outcome, $Y_i(1)$, is whether an individual re-offends after being prosecuted. The untreated potential outcome, $Y_i(0)$, is whether an individual re-offends after being dismissed.

We start by defining discrimination as the racial gap in prosecution rates between individuals who would have the same re-offence outcome if prosecuted, $Y_i(1)$. We later discuss racial gaps between people with the same i) re-offence outcome if dismissed, or ii) impact of prosecution, as well as empirical and conceptual reasons to prefer one over another. Since $Y_i(1)$ is binary in this example, the distribution of re-offence outcomes if prosecuted within each racial group is given by the share of individuals of each group who have $Y_i(1) = 1$. For each racial group r , this is the “average prosecuted outcome” – the average re-offence outcome that would be realized if everyone were prosecuted.

If the average prosecuted outcome varies by race, we estimate discrimination conditional on the prosecuted outcome in three steps. First, we estimate prosecution rates that are conditional on prosecuted outcome and race by rescaling observed race-specific prosecution rates (Arnold, Dobbie, and Hull, 2022). Second, using the resulting race- and prosecuted outcome-specific prosecution

⁴We discuss conditioning on multi-valued potential outcomes in the sections below.

rates, we estimate racial gaps in prosecution for people who: a) would re-offend after prosecution ($Y_i(1) = 1$) and b) would not re-offend after prosecution ($Y_i(1) = 0$). Third, we estimate average discrimination conditional on having the same prosecuted outcome by computing a weighted average of the prosecuted outcome-specific racial gaps from the second step, where the weights are the overall share of people who would re-offend after prosecution.

Since potential outcomes are selectively observed, we cannot directly observe the average prosecuted outcome for each racial group in the data, but we estimate it using an IV framework. For now, assume that we have access to a natural experiment that quasi-experimentally shifts treatment rates – prosecution rates in this example – and takes the form of a binary IV. Under standard IV assumptions, each racial group is partitioned into i) always takers, ii) compliers, and iii) never takers, and the average prosecuted outcomes of always takers and compliers can be estimated using the data (Imbens and Rubin, 1997). To identify average prosecuted outcomes for never takers, we restrict the relationship between likelihood of prosecution and average prosecuted outcomes. In our preferred approach, we assume this relationship is weakly monotonic. For example, if compliers are more likely than always takers to re-offend if prosecuted, weak monotonicity implies that never takers must be at least as likely as compliers to re-offend if prosecuted. This assumption yields bounds for the average outcomes that would be realized in a counterfactual where everyone in a given racial group were prosecuted, and consequently yields bounds for average discrimination conditional on prosecuted outcome (Kowalski, 2023a).^{5,6}

Estimating discrimination using a DiD strategy, as in our main application where a budget reform affects only one county, requires additional assumptions. This is because it is difficult to disentangle the impacts of the reform from the effects of time, and to pin down the proportions and average outcomes of always takers, compliers and never takers. We assume that i) time trends do not affect treatment (prosecution in this case) and ii) average prosecuted outcomes evolve similarly over time for always takers and compliers and is independent of county. The first assumption ensures that always takers, compliers and never takers are defined as they would with a binary instrument, since only the reform (and not time) shifts treatment. Combining this with the second assumption, the change in outcomes experienced by prosecuted individuals in the “no-reform” counties is a valid estimate of the change in prosecuted outcomes that always takers and compliers in the *county that adopted the reform* would have experienced if the reform had not occurred.⁷ This adjustment allows us to use a DiD to estimate average prosecuted outcomes by race group, and estimate discrimination conditional on prosecuted outcomes as described above.⁸

⁵Stronger assumptions on the relationship between selection into treatment and potential outcomes (e.g. assuming it is linear) point-identifies average potential outcomes. This approach involves estimating the set of marginal treatment response functions and integrating them (Mogstad, Santos, and Torgovitsky, 2018).

⁶Jordan (2024) imposes a mathematically similar restriction by modelling the underlying objectives of randomly assigned felony review prosecutors. Our approach places restrictions on the natural experiment instead. This allows decision-makers to adopt complex and multi-dimensional models as long as their decisions generate patterns that are consistent with the assumptions on the relationship between selection into treatment and average potential outcomes.

⁷This extends the logic of the “time-corrected” Wald estimator of local average treatment effects using DiD designs to estimate average potential outcomes instead (De Chaisemartin and D’Haultfœuille, 2018).

⁸We also discuss the assumptions required to use a DiD to estimate average untreated outcomes, and provide

We apply this approach to study racial discrimination in misdemeanor prosecution. We estimate bounds for the race-specific average re-offence outcome if everyone were prosecuted using a large, unanticipated cut to the Prosecutor’s Office budget in King County, Washington (Seattle + surroundings). Using administrative court records from Washington State, we employ a DiD strategy comparing King County to adjacent counties. The budget cut reduced prosecution rates by 20% and the likelihood of being charged with a new offence in the following year by 13–15%.⁹

Using the shifts in prosecution rates and re-offence outcomes generated by this natural experiment, we find meaningful racial differences in the unobserved outcomes if prosecuted. Prior to the budget reform, 24.5–29.3% of white defendants would commit a new offence if prosecuted, while the same is true for 32.3–37.1% of minority defendants.¹⁰ These estimates imply that minority defendants in this context would be 3–12.6 p.p. (10.2–51.4%; $p = 0.004$) more likely to commit a new offence after prosecution than their white counterparts. Since there are racial differences in unobserved potential outcomes in this context, raw or covariate-adjusted racial gaps in prosecution, which do not account for these differences, would be biased.

We use the estimates of the average outcomes if everyone were prosecuted to estimate bounds for racial differences in prosecution conditional on the outcome if prosecuted. We find no racial gap in prosecution rates before the budget reform. This changes after the reform – even though prosecution rates fall overall, white defendants were 1.3–4 p.p. (1.8–5.6%) more likely than minority defendants to be prosecuted, after conditioning on racial differences in the unobserved outcome if prosecuted.¹¹ Alternative approaches to estimate discrimination lie outside our estimated bounds (the covariate-adjusted racial prosecution gap after the reform is 4.4 p.p.).

A potential explanation for the relatively higher post-reform prosecution rate for white defendants is that minority cases might be backed up by weaker evidence, perhaps due to discrimination in previous stages of the criminal legal system (Goncalves and Mello, 2021; Owens and Ba, 2021). At a time when they are facing budget cuts, prosecutors would also be less likely to pursue weak, low quality cases since they will have to work relatively harder for prosecution to be successful. We would expect to see more pronounced racial gaps within a subset of cases that are likely weak if prosecutors selectively drop such cases due to the reform, and if such cases are more common among minority defendants.

We test this explanation by using pre-reform data to classify offence types based on the share of charges that are successfully sentenced, a proxy for case quality. We split our sample into ‘high quality’ (drug, DUI, property, etc.) and ‘low quality’ offences (traffic, other and violent offences), based on this proxy.¹² Repeating our discrimination estimation within each subsample, we find

empirical validation for all of these assumptions when discussing the relevant application.

⁹The direction and magnitude of these estimates are consistent with the impact of diversion and non-prosecution for low-level offences in other settings (Mueller-Smith and Schnepel, 2021; Agan, Doleac, and Harvey, 2023).

¹⁰We define a broad ‘minority’ out-group because Native Hawaiian and Pacific Islanders individuals also face disadvantage in Washington (Hu and Esthappen, 2017; Malott, 2024). Our results are also robust to defining the out-group as Black & Hispanic individuals.

¹¹Our results are qualitatively similar if we estimate discrimination between individuals who would have the same re-offence outcome if dismissed instead.

¹²This exercise is only suggestive because case quality may not be the only factor that varies between these two

that the post-reform racial gaps are driven by the ‘low quality’ subset of cases. Conditional on unobserved re-offence outcomes if prosecuted, white defendants after the reform are 1.6–4.6 p.p. more likely to be prosecuted than their minority counterparts. This post-reform gap is muted in the ‘high quality’ subsample (0.2–1.1 p.p.).

These results provide suggestive evidence that prosecutors were prosecuting most cases before the reform, and passing through any pre-existing disparities from prior stages in the criminal legal system. However, in shifting their focus to high quality cases after the budget cuts, they may have attenuated disparities from prior stages in the criminal legal system. This behaviour is consistent with recent work showing that prosecutors sometimes use their discretion to attenuate discrimination from pre-prosecution decisions (Harrington and Shaffer, 2023).

Supplementary results show how prosecution patterns vary by the potential outcomes of defendants. We find that prosecution is less likely for defendants who **would** commit a new offence despite prosecution ($Y_i(1) = 1$) than for those who **would not** ($Y_i(1) = 0$). An auxiliary exercise estimating prosecution rates separately by the treatment effect of prosecution ($Y_i(1) - Y_i(0)$) provides suggestive evidence that prosecution is less common for cases where it would generate new crime. These patterns are consistent with recent work finding that prosecutors may choose not to prosecute defendants who have high risk of future contact with the criminal legal system (Agan, Doleac, and Harvey, 2023; Harrington, Murdock III, and Shaffer, 2023).

In a second application, we study SES discrimination in the decision to promote 3rd graders in Michigan Public schools to 4th grade (D_i). Here, we estimate bounds for SES differences in promotion rates for students who would achieve the same success if promoted to 4th grade ($Y_i(1)$), which educators say is a key concern underlying promotion decisions. Our measure of $Y_i(1)$ is whether students achieve the Michigan Department of Education guidelines for proficiency in English and Math standardized tests, if promoted to 4th grade. We refer to such students as “succeeding” in 4th grade. We estimate whether underlying success in 4th grade varies by SES using an RD design generated by Michigan’s “Read by Grade 3” law. Due to this law, the probability of being promoted to the 4th grade discontinuously increased at a cut-off around the 5th percentile of the 3rd grade standardized test score distribution (Berne et al., 2023).

We find meaningful SES differences in the average 4th grade success rates that would be realized if all students at the test score cut-off were promoted. At the cut-off, which is at the low end of the test score distribution, only [pending disclosure] of low SES students would succeed if promoted while [pending disclosure] of high SES students would succeed if promoted. These differences imply that low SES students in this context are [pending disclosure] less likely to succeed if promoted to 4th grade than their high SES counterparts. Given these large and meaningful SES differences in underlying potential outcomes, raw or covariate-adjusted promotion gaps will provide incorrect estimates of discrimination.

We find evidence of discrimination in student grade promotion, even after accounting for SES differences in underlying success rates. Our bounds imply that high SES students at the cut-off are

categories of offence types. For example, these offences might require different amounts of resources.

[pending disclosure] more likely to be promoted than low SES students. Supplementary exercises i) show that this gap is due to the promotion of students who would not succeed if promoted, ii) show that it is not driven by differential parental involvement, and iii) discuss extrapolating estimates away from the cut-off to elsewhere in the analysis window. Crucially, alternative estimates of discrimination that do not adjust for differences in potential 4th grade success lie outside our estimated bounds (the covariate-adjusted SES promotion disparity is [pending disclosure]).

This project makes several methodological and empirical contributions. First, we add to the large literature on discrimination and its measurement (Becker, 1957; Aigner and Cain, 1977; Phelps, 1972; Arrow, 1973; Arnold, Dobbie, and Yang, 2018) by demonstrating how to use natural experiments to obtain bounds or point estimates of discrimination conditional on potential outcomes or treatment effects. Recent methodological work on discrimination conditional on unobservable factors relies on randomly assigned decision-makers and conditions on the potential outcome in a single treatment state (Arnold, Dobbie, and Hull, 2022). As a final methodological point, we add to the literature mapping DiD to IV by showing how to use DiD variation to estimate average potential outcomes.

Second, we contribute to our understanding of criminal prosecution. Our results in Washington represent the first evidence of racial discrimination in misdemeanor prosecution that documents unobservable racial differences and directly accounts for them. We find patterns consistent with recent work showing how prosecutors use their discretion to attenuate discrimination in earlier stages of the criminal legal system (Harrington and Shaffer, 2023; Jordan, 2024), rather than amplify them (Kutateladze and Andiloro, 2014; Rehavi and Starr, 2014; Tuttle, 2023). Consistent with the literature on the impacts of prosecution, our assessment of the King County budget cut suggest that non-prosecution for minor offences reduces future criminal activity.

Third, while there is descriptive evidence of disparities in student promotion decisions (Locke and Sparks, 2019; Moller et al., 2006), our analysis in Michigan Public Schools provides the first evidence of SES discrimination in student promotion that accounts for unobservable differences. Our results show that the promotion disparities documented in recent work on Michigan’s “Read by Grade 3” law are not solely due to differences in underlying unobservables (Westall et al., 2022b).

2 Estimands of interest

We begin with a general potential outcomes framework (Imbens and Angrist, 1994). Individuals are chosen for a binary treatment, D_i , based on some function of the unobservable potential outcomes. Individuals realize the potential outcome associated with chosen treatment state, $Y_i(D_i)$. Each respective potential outcome is only observed if the associated treatment state is realized. That is, the treated potential outcome, $Y_i(D_i = 1)$, is only observed for individuals who are treated. Similarly, the untreated potential outcome, $Y_i(D_i = 0)$, is only observed for individuals who are not treated. These potential outcomes may be continuous, discrete or binary. Individuals belong to one of two groups, denoted by $R_i \in \{r_1, r_2\}$ and the distribution of potential outcomes may differ

across groups.¹³

Our goal is to quantify discrimination, defined as group differences in treatment rates for individuals with the same potential outcome. We begin by estimating differential treatment between individuals who would realize the same outcome **if they were treated**.¹⁴ In Section 3, we also discuss conditioning on outcome if not treated and the treatment effect. Which is most appropriate may depend on the particular context. The notion of discrimination conditional on potential outcomes, formally described in Definition 1 for the treated potential outcome, maps to classic notions of fairness and discrimination in economics that focus on whether people of two different groups are being treated differently, despite being identical in some objective but latent quality. For example, this notion would consider racial gaps in hiring rates between people who would be equally-productive if they were hired as discrimination (Aigner and Cain, 1977). This definition also encompasses multiple sources of discrimination (statistical discrimination, animus and biased beliefs) and is consistent with the legal interpretation of ‘disparate impact’ (Becker, 1957; Phelps, 1972; Arrow, 1973; Bordalo et al., 2016; Bohren et al., 2019; Arnold, Dobbie, and Hull, 2022).

Definition 1. Differential treatment conditional on treated potential outcome $Y_i(1)$

$$E[D_i|R_i = r_1, Y_i(1) = y] - E[D_i|R_i = r_2, Y_i(1) = y]$$

While this definition represents an ideal measure of discrimination, it is generally difficult to estimate empirically. Since treated outcomes are only observed among treated individuals, it is not feasible to directly condition on $Y_i(1)$ to estimate the quantity in Definition 1. One approach to estimate discrimination might be to compute the raw gap in treatment rates by group, $E[D_i|R_i = r_1] - E[D_i|R_i = r_2]$. However, this will differ from the quantity in Definition 1 if treatment decisions are a function of $Y_i(1)$, and if the distribution of $Y_i(1)$ varies by group.

An alternative approach might be to compute the treatment gap, conditional on a set of observed covariates. This ‘selection-on-observables’ approach alters the interpretation of the discrimination test. Instead of measuring the extent of differential treatment between people who have the same potential outcome but different group membership, it moves towards a narrower test measuring how much two individuals with identical **observables** are treated differently **because** of their group identity, generating ‘included variables bias’ (Ayres, 2010). In general, even if such bias is small, controlling for covariates will typically not recover the measure of differential treatment, conditional

¹³This framework is a general version of the potential outcomes framework described in Arnold, Dobbie, and Hull (2022). In their setting of bail reform, individuals vary in a latent unobservable Y^* , which is only observed among treated (released) individuals, while no outcome is observed for untreated (detained) individuals. We consider a framework that applies to settings where untreated outcomes are also selectively observed among those not treated. For instance, in our main application we selectively observe potential recidivism outcomes if prosecuted and if not prosecuted.

¹⁴This approach requires the researcher to specify a particular set of potential outcomes, $Y_i(D_i)$, to condition on. It is possible that the underlying decision-makers also value other factors that are not captured by the $Y_i(D_i)$ that we choose (Kleinberg et al., 2018). If the relationship between such omitted factors and our chosen $Y_i(D_i)$ varies by group, this definition would not quantify differential treatment conditional on all unobservable factors. However, such gaps can still be interpreted as unwarranted disparities if conditioning on our chosen $Y_i(D_i)$ maps to a well-defined notion of fairness.

on potential outcome, in Definition 1 unless the covariate used is perfectly correlated with $Y_i(1)$.

In practice, groups often differ in terms of unobservable potential outcomes in many settings where measuring discrimination is of interest. For example, relevant to our primary application studying racial discrimination in misdemeanor prosecution, discrimination in prior decision points of the criminal legal system, e.g., policing, could generate cross-race differences in the underlying potential outcome distributions. In the context of our application studying socio-economic discrimination in students' promotion decisions, differential access to educational inputs by socio-economic status might generate differences in skills (and thus potential outcomes) between the two groups. The estimand described in Definition 1 measures discrimination holding such upstream differences fixed. By doing so, this measure focuses on how much discrimination arises in the decision process of interest.

We next demonstrate how to identify the estimand in Definition 1 by using a natural experiment. Consider a quasi-random intervention that generates a binary instrument, Z . Assume Z satisfies the usual instrumental variables (IV) assumptions of relevance, independence, exclusion and monotonicity. In our main application, we use a difference-in-difference (DiD) approach to isolate quasi-random shifts in treatment. Time trends in potential outcomes and treatment status that are inherent in a DiD approach can act as confounders and make it difficult to use DiD variation in an IV set up. For ease of exposition, we abstract away from time trends for now and let Z be a binary instrument, where $Z \in \{0, 1\}$ denotes periods before and after some intervention. We first discuss identification and measurement of the discrimination estimated in Definition 1 using this binary instrument. We then address the adjustments required for the identification using a DiD approach in Section 3.

Definition 2 describes a time period-specific version of Definition 1, a group treatment gap that is specific to a given period and value of the treated outcome (Δ_{zy}). Each such gap is composed of treatment rates that are conditional on period, group and potential outcome (π_{zry}).

Definition 2. Differential treatment within a given period, conditional on $Y_i(1)$

$$\begin{aligned}\Delta_{zy} &= (E[D_i|Z = z, R_i = r_1, Y_i(1) = y] - E[D_i|Z = z, R_i = r_2, Y_i(1) = y]) \\ &= (\pi_{zr_1y} - \pi_{zr_2y}) \\ \Delta_z &= \sum_{y \in \text{supp}(Y_i(1))} Pr(Y_i(1) = y) \Delta_{zy}\end{aligned}\tag{1}$$

Our main objects of interest are the period-specific estimates of discrimination that are conditional on having the same outcome if treated (Δ_z). These are weighted averages of the period- and treated outcome-specific gaps, where the weights are given by the proportion of people in the entire population that have a particular value of the treated potential outcome ($Pr(Y_i(1) = y)$). These can further be used to construct measures of changes in discrimination **due to the intervention**, $\Delta_{z=1} - \Delta_{z=0}$, the difference in discrimination before versus after some intervention.¹⁵

¹⁵Even though Z represents quasi-experimental variation, the cross-group gap in the impact of Z on D will not

To understand how to estimate our main object of interest, note that the building blocks of Δ_z are treatment rates that are conditional on period, group and treated outcome (π_{zry}). Since treated outcomes are not always observed, we cannot directly condition on it to compute each π_{zry} . However, following Arnold, Dobbie, and Hull (2022), we re-write π_{zry} in Equation 2 using: 1) the definition of conditional expectations, and 2) the IV assumptions. The second line follows from the definition of conditional expectations, while the third line follows from the fact that $Y_i(1) \perp Z$.

$$\begin{aligned}\pi_{zry} &\equiv E[D_i|Z = z, R_i = r, Y_i(1) = y] \\ &= \frac{E[Y_i(1) = y|Z = z, R_i = r, D_i = 1] \times E[D_i|Z = z, R_i = r]}{E[Y_i(1) = y|Z = z, R_i = r]} \\ &= \frac{E[Y_i(1) = y|Z = z, R_i = r, D_i = 1] \times E[D_i|Z = z, R_i = r]}{E[Y_i(1) = y|R_i = r]}\end{aligned}\tag{2}$$

Equation 2 highlights how to quantify the period-, group-, and potential-outcome specific treatment rates used to estimate discrimination conditional on having the same outcome if treated (Δ_z). We need the following objects:

1. $E[D_i|Z = z, R_i = r]$:
Share of individuals of each group r treated in each period z
2. $E[Y_i(1) = y|Z = z, R_i = r, D_i = 1]$:
Share of treated individuals with treated outcome y , for each group r and period z
3. $E[Y_i(1) = y|R_i = r]$:
Prevalence of treated potential outcome y in each group's population

Each period-, group-, and potential-outcome specific treatment rate π_{zry} is a function of two moments typically directly observable in data, and one typically unobserved moment. Objects 1 and 2 are observed in data – we can see the share of individuals of each group who are treated, and the outcomes realized for treated individuals. Object 3 is unobserved, since it represents the underlying share of individuals of group r who would experience a given value of the treated potential outcome, which would only be observed in a counterfactual where everyone of that group was treated. This share is an especially crucial element because it also provides a test of whether the distribution of potential outcomes varies by group. If the distributions are the same across race, we could interpret the raw observed group differences in treatment as discrimination. We also use $E[Y_i(1) = y|R_i = r]$, along with each group's shares of the population (p_r), to compute the underlying prevalence of treated potential outcome y in population: $E[Y_i(1) = y] = p_{r_1}E[Y_i(1) = y|R_i = r_1] + p_{r_2}E[Y_i(1) = y|R_i = r_2]$. We use this to aggregate each π_{zry} to estimate the discrimination conditional on having the same outcome if treated in a given period (Δ_z) in Definition 2.

generally recover $\Delta_{z=1} - \Delta_{z=0}$ unless 1) potential outcomes are similar across group or 2) the impact of Z on D is uncorrelated with potential outcomes. See Appendix C.1 for details.

However, $E[Y_i(1) = y | R_i = r]$ is not typically directly observable in the data, unless there are unique institutional features such as random assignment to supremely lenient decision-makers who treat (almost) everyone (Arnold, Dobbie, and Hull, 2022; Baron et al., 2023; Reeves, 2023). There are many settings where measuring discrimination is of interest, but decision-makers are not randomly assigned. For instance, in the settings considered in this paper, criminal misdemeanor defendants in King County are not randomly assigned to prosecutors, and students in Michigan public schools are not randomly assigned to teachers. Measuring discrimination in prosecution or students’ promotion decisions in these contexts is thus difficult if the distribution of potential outcomes varies by group.

In the following section, we incorporate insights from the IV and marginal treatment effects literatures to estimate $E[Y_i(1) = y | R_i = r]$, which we need to understand if the groups to be compared differ in terms of the potential outcomes if treated. If so, we adjust for such differences following [Equation 2](#), and then measure discrimination that accounts for differences in potential outcomes.

3 Estimating discrimination using a natural experiment

In this section we discuss using a binary instrumental variable (IV) to understand if the distribution of potential outcomes varies by group, e.g., race, using insights from the IV and marginal treatment effects literature. First, we describe estimating the share of each group that would experience a given **treated** potential outcome if everyone of that group were treated. This is a key input in estimating discrimination that is conditional on treated potential outcomes. We then discuss accounting for complications that arise when using difference-in-difference (DiD) variation for this purpose. Finally, we discuss conditions required to account for group differences in **untreated** potential outcomes or **treatment effects** instead, which we also apply in our main application.

3.1 Implementation with a binary instrument

We describe the framework in the context of racial discrimination in misdemeanor prosecution. Individuals belong to either ‘White’ or ‘Minority’ groups, denoted by $R_i \in \{w, m\}$, and the treatment decision is prosecution. This definition of racial groups, rather than a White–Black comparison, is motivated by the context of Washington State, which we describe in detail in [Section 5](#). We start with a discussion of estimating racial differences in prosecution rates for individuals who would have the same outcome if prosecuted, i.e. treated. Later, we discuss conditioning on the outcome if dismissed, or the treatment effect of prosecution.

Individuals, indexed by i , are chosen for treatment, D_i . In the context of prosecution, this decision is made by a bundle of multiple agents who influence case outcomes, including prosecuting attorneys and judges, rather than by the individual i . Let $D_i = 1$ if an individual’s case is prosecuted, and $D_i = 0$ if an individual’s case is dismissed. Let the potential outcomes be binary indicators for whether an individual commits a new offence in the future, after prosecution or

dismissal, i.e., $Y_i(D_i) \in \{0, 1\}$. We use binary potential outcomes for the rest of this section for simplicity. However, note that the expressions in Definition 2 and Equation 2 accommodate multi-valued potential outcomes.

Finally, let Z be a binary instrument that shifts the rate of prosecution. Let Z represent periods before and after an unanticipated budget cut that sharply reduced prosecution rates. As described in the previous section, our application isolates the quasi-experimental variation using a difference-in-difference (DiD) strategy in which one county adopts a reform and the others do not. The time trends inherent in this approach make directly using an IV challenging. For ease of exposition, we first abstract away from time trends and discuss how a binary IV identifies the required moments. We then make adjustments for the DiD in the following subsection.

Recall that we need to estimate each period-, group- and potential outcome-specific treatment rate (π_{zry}) in Equation 2 to quantify the discrimination estimands in Definition 2. The key challenge is that the denominator, $E[Y_i(1) = y | R_i = r]$, is unobserved. Surmounting this challenge requires estimating the proportion of each group r that would realize treated outcome $Y_i(1) = y$ if everyone in that group were treated. Since $Y_i(1)$ is binary for simplicity, $E[Y_i(1) = 1 | R_i = r]$ is the average outcome that people in group r would realize if everyone in that group were treated. We next show how to use the binary instrument Z to estimate bounds and point estimates of $E[Y_i(1) = 1 | R_i = r]$, separately by race.

Under the IV assumptions listed in Section 2, the variation from the binary instrument Z partitions the population into three “compliance groups” (always takers, compliers and never takers) and identifies their associated proportions and average potential outcomes (Angrist, Imbens, and Rubin, 1996). Assuming that Z shifts treatment for both racial groups, these quantities are identified separately by race group. For each race, we directly observe the proportions of always takers (p_A) and compliers (p_C) in the data by examining the share of the population that would receive treatment regardless of the reform and would only receive treatment because of the reform, respectively. In our application, the treatment is prosecution, and the reform decreases prosecution rates. Here, p_A is the share of people who are prosecuted after the budget cut, and p_C is the change in prosecution rates due to the budget cut. Since always takers, compliers and never takers partition the population, the share of never takers is $p_N = 1 - p_A - p_C$.

The variation from the binary IV also provides estimates for average potential outcomes for some of these groups. Since our initial focus is on treated potential outcomes, we concentrate on that potential outcome here. In our main application, the average treated outcome for always takers is the average outcome of people treated (i.e., prosecuted) after the budget cut. Note that the group of people treated before the budget cut consist only of compliers and always takers, since never takers are never treated. Hence, the average outcome of people treated before the reform is a weighted average of treated outcomes for compliers and always takers. Using these two averages, along with the population shares of always takers and compliers, we estimate the average treated outcomes of compliers (Imbens and Rubin, 1997). This recovers average treated outcomes for two of the three “compliance groups” that partition the population: always takers and compliers.

However, we do not observe the average treated outcomes of never takers, since they are never treated. This is the final piece to estimate the average outcome that would be realized if everyone of each race group were treated, $E[Y_i(1) = 1 | R_i = r]$.¹⁶

We estimate bounds (or point estimates) for the average treated outcomes of never takers by placing restrictions on the relationship between the propensity to be treated and average treated outcomes. Each “compliance group” differs, by definition, in their propensity to be treated. Always takers are more likely to be treated than compliers, who are in turn more likely to be treated than never takers (Angrist, Imbens, and Rubin, 1996). [Figure 1](#) depicts a hypothetical example where always takers and compliers are roughly 70% and 20% of the population respectively. In this example, compliers have greater treated outcomes than always takers, which would be the case if prosecutors were more likely to prosecute individuals less likely to commit a new offence if prosecuted. Note that this relationship is estimated using the average treated outcomes identified by the binary IV, along with standard IV assumptions.

In Panel a) we assume that the relationship between the underlying treatment propensity and treated outcomes is weakly monotonic, similar to Mogstad, Santos, and Torgovitsky (2018); Kowalski (2023a). This assumption extends the relationship between always takers’ and compliers’ average treated outcomes to never takers’ average treated outcomes. In this example, the assumption implies that the average treated outcomes for never takers must be weakly greater than the average treated outcomes for compliers, which pins down the lower bound for never takers’ outcomes. Intuitively, we are assuming that never takers are at least as likely as compliers to commit a new offence if prosecuted. Since $Y_i(1) \in \{0, 1\}$, the average treated outcomes for never takers is bounded above by one.¹⁷ Combining the bounds on the treated outcomes for never takers with the average treated outcomes for compliers and never takers yields bounds on the average treated outcomes in each group’s subsample, $E[Y_i(1) = 1 | R_i = r]$.¹⁸

We obtain point estimates instead if we restrict the relationship between the underlying treatment propensity and treated outcomes to be linear. Panel b) of [Figure 1](#) demonstrates this, where the diamonds plot the treated outcomes for the median always taker and complier against their respective treatment propensities.¹⁹ Assuming this relationship is linear allows us to extrapolate the treated outcomes across the support of the treatment propensity and point-identify the treated outcomes of never takers. This restriction also identifies the marginal treated outcome function ($MTO(p)$) which is integrated to estimate $E[Y_i(1) = 1 | R_i = r]$ (Heckman and Vytlacil, 2000;

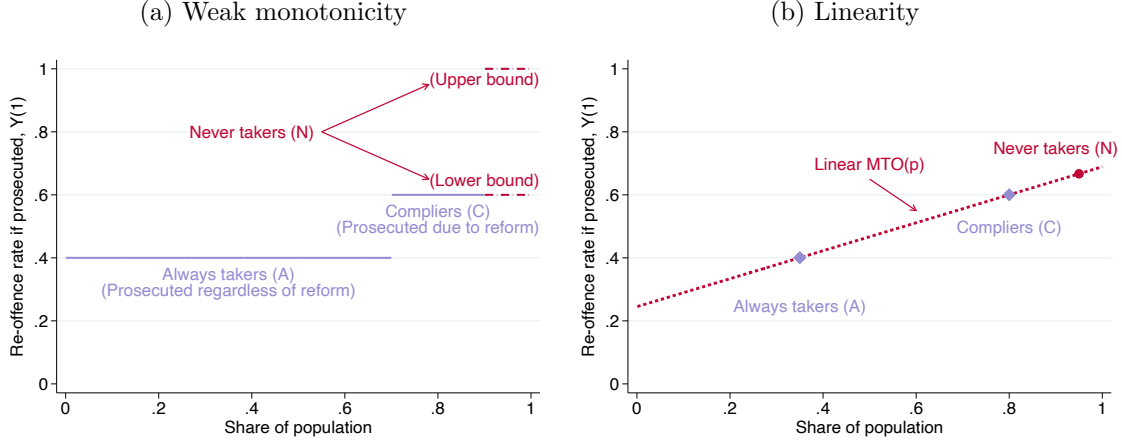
¹⁶When both a natural experiment and randomly assigned decision-makers are present, the approach that identifies outcomes using information with a larger proportion of treated (or untreated, depending on the context) individuals will require less extrapolation and involve less extrapolation error.

¹⁷This restriction is mathematically similar to the “Performance Bound” in Jordan (2024), who studies racial discrimination in felony review in a context with randomly assigned prosecutors. However, those bounds arise from modelling the underlying objectives of prosecutors, while ours place restrictions on the policy reform.

¹⁸If potential outcomes are multi-valued, we can still use this approach. In such a case, we require an estimate of the prevalence of each possible value of the potential outcome, $E[Y_i(1) = y | R_i = r]$, to identify the discrimination estimand in Definition 2. The logic underlying the bounding approach will still hold, since each expectation $E[Y_i(1) = y | R_i = r]$ represents a population prevalence and is hence also bounded between $[0, 1]$.

¹⁹Linearity and the uniformity of the underlying latent index determining treatment implies that the median outcome of each compliance group has the average treated outcome of that compliance group (Kowalski, 2023b).

Figure 1: Identifying the average treated outcome with a binary IV



Note: This figure uses simulated data. Lower values of the x-axis denote individuals who are more likely to be treated. $Y(1)$ denotes the treated potential outcome. The diamonds and dots in Panel b) reflect outcomes of the median individual in that group. Solid lines and diamonds represent moments observed in the data, and dashed lines and circles represent objects that are extrapolated.

Brinch, Mogstad, and Wiswall, 2017; Mogstad, Santos, and Torgovitsky, 2018; Kowalski, 2023b).²⁰

Note that the restrictions that we place to bound average treated outcomes are restrictions on the natural experiment and require assuming the underlying decision-makers focus on a single narrow objective. Rather, this approach allows decision-makers to adopt a wide range of complex and multi-dimensional models as long as their decisions generate patterns that imply that the relationship between average potential outcomes for each of the compliance groups is weakly monotonic in their likelihood of being treated. In the example in Panel a) of Figure 1, if prosecutors followed a decision model that meant never takers were less likely than compliers to re-offend if prosecuted, this would violate our assumption.²¹ On the other hand, the linear restriction involves identifying the marginal treatment response functions and assuming they are linear, which is a stronger assumption.

Implementing this separately by race group r provides either bounds or point estimates for the average outcome that would be realized if everyone of each group were treated, $E[Y_i(1) = 1 | R_i = r]$. This is the final object that we need to estimate discrimination that is conditional on treated potential outcomes, reproduced below for the case of binary treated outcomes in Equation 3.

²⁰Linearity assumptions identify all the marginal treatment response functions. We identify the marginal untreated outcome function by using the average untreated outcomes for compliers & never takers to extrapolate the untreated outcome for always takers. Along with $MTO(p)$, this identifies the marginal treatment effect function. Appendix C.2 sketches a simple model of selection, describes these assumptions, and illustrates this point-identification approach with a brief empirical example studying discrimination in incarceration decisions in Texas.

²¹If decision-makers behave in a way that violates this assumption, an alternative bounding approach is to estimate worst case bounds, since this is an exercise in bounding a proportion, which must lie in $[0, 1]$ (Manski, 1990).

$$\begin{aligned}
\pi_{zr1} &= \frac{\overbrace{E[Y_i|Z = z, R_i = r, D_i = 1] \times E[D_i|Z = z, R_i = r]}^{\text{Observed in data}}}{\underbrace{E[Y_i(1) = y|R_i = r]}_{\text{Extrapolated}}} \\
\pi_{zr0} &= \frac{\overbrace{E[(1 - Y_i)|Z = z, R_i = r, D_i = 1] \times E[D_i|Z = z, R_i = r]}^{\text{Observed in data}}}{\underbrace{1 - E[Y_i(1) = y|R_i = r]}_{\text{Extrapolated}}} \\
\Delta_{zy} &= \pi_{zwy} - \pi_{zby} \\
\Delta_z &= \sum_{y \in \{0,1\}} Pr(Y_i(1) = y) \Delta_{zy}
\end{aligned} \tag{3}$$

We observe the re-offence rate among prosecuted individuals in each period, Z and race in the data: $E[Y_i|Z = z, R_i = r, D_i = 1]$. We also observe the prosecution rate for each period and race: $E[D_i|Z = z, R_i = r]$. Plugging the bounds/point estimates for $E[Y_i(1) = 1|R_i = r]$ into the first two lines of Equation 3 generates bounds/point estimates for each period-, race- and potential outcome-specific treatment rate, π_{zry} . Using π_{zry} in the third line yields bounds/point estimates for the period- and outcome-specific discrimination Δ_{zy} . We then construct the period-specific discrimination estimates, Δ_z , as a weighted average of the period- and potential outcome-specific discrimination, where the weights are defined by the prevalence of the treated outcome in the population, $Pr(Y_i(1) = 1)$ (fourth line of Equation 3).

3.2 Accommodating difference-in-difference into the approach

So far, we have discussed using a binary IV to assess if treated outcomes differ by group (e.g., race) and estimate discrimination, conditional on treated outcomes. As discussed earlier, not all natural experiments easily map to the IV framework that is crucial for our approach. This is especially true for our main application with a DiD approach using the timing of a budget reform adopted in one county but not others. Due to time-variation in outcomes, if we used a binary IV, e.g., before vs after the reform, we would not be able to disentangle changes in outcomes that are due to the reform from the effects of time.

We overcome this complication by using the change in treated outcomes in counties that did not adopt a reform as an estimate of the change in treated outcomes the county that adopted the reform would have experienced had it not adopted the reform. This assumes that 1) time alone does not influence treatment status, and 2) that the time trend in average treated outcomes are the same for always takers and compliers, and are independent of county. These assumptions need to hold within the groups (e.g., race) that we are trying to compare. Next, we introduce additional notation to formalize the assumptions and describe the adjustment. In keeping with the previous subsection, we follow the same example of measuring discrimination in prosecution, conditional on

the prosecuted outcome using a budget cut that reduces prosecution rates. Appendix C.3 discusses the adjustment in further detail in a more general framework.

Let $T \in \{0, 1\}$ denote periods before/after the reform, and let $G \in \{0, 1\}$ denote the county that adopted the reform. Let $Z \equiv T \times G$ be an indicator for after the reform and in the county that adopted the reform. $D_i(g, z) \in \{0, 1\}$ denotes whether an **individual** takes up treatment or not (i.e., is prosecuted or not). This is a key feature of the IV framework that differs from typical DiD implementations. Here, it is not the case that an entire county is “treated” by the budget reform. Rather, the budget reform shifts individuals into or out of treatment. As a result, individuals in either county can be treated both before or after the policy. The lack of a time subscript in the treatment indicator implicitly makes the first assumption – time does not influence treatment status. Similar to the monotonicity assumption in IV, we allow the reform to shift individuals into or out of treatment in only one direction.

This assumption allows us to partition the population of individuals in the county that adopts the reform ($G = 1$) into always takers (A), never takers (N) and compliers (C), since their proportions are constant over time. Equation 4 demonstrates how to estimate each of these in the data, following our main example where the reform reduces treatment rates.

$$\begin{aligned} p_A &= E[D_i|G = 1, T = 1] \\ p_N &= 1 - (E[D_i|G = 1, T = 0]) \\ p_C &= 1 - (p_A + p_N) \end{aligned} \tag{4}$$

Since time trends are still allowed to affect potential outcomes, the treated potential outcomes for each of these groups is not directly observed in both periods. In a setting where a reform reduces treatment take-up, the outcomes of individuals who are treated after the reform identifies the treated outcomes for always takers in $G = 1$. Equation 5 demonstrates that the treated outcomes for always takers in the post-period and in the pre-period differ by the trend in treated potential outcomes, θ_1 (second line of Equation 5), which is unobserved.

$$\begin{aligned} E[Y_i|D_i = 1, G = 1, T = 1] &= E[Y_{i1}(1, 1)|A, G = 1] \\ \underbrace{E[Y_{i1}(1, 1)|A, G = 1]}_{\text{Observed}} &= \underbrace{E[Y_{i0}(1, 1)|A, G = 1]}_{\text{Unobserved}} + \underbrace{\theta_1}_{\text{Unobserved}} \end{aligned} \tag{5}$$

We identify θ_1 by making an assumption in the spirit of parallel trends. Equation 6 formally describes this, where $Y_{it}(1, g)$ is an individual’s treated potential outcome. We assume that the average change in treated outcomes is the same for always takers and compliers, and is independent of county. This restricts the effects of time on treated potential outcomes to be constant across these two compliance groups, but not all of them, and does not force the effects of time to be

identical across individuals.²²

$$E[Y_{i1}(1, g) - Y_0(1, g)|g, \text{Always taker}] = E[Y_{i1}(1, g) - Y_0(1, g)|g, \text{Complier}] \text{ and } \perp g \quad (6)$$

Under these two additional assumptions, the change in outcomes among treated individuals in the counties that did not adopt the reform provides an estimate of the trend in treated outcomes: $\theta_1 = E[Y_{i1}(1, 0) - Y_{i0}(1, 0)|G = 0]$. We estimate θ_1 and use it to separate the reform’s impact on treated outcomes from the effects of time. This allows us to estimate average treated outcomes for always takers and compliers before and after the reform, in the county that adopted the reform. We use these moments to bound or point identify the average outcomes for never takers before and after the reform. The only difference from the approach with a simple binary IV is that the average treated outcomes for each compliance group vary over time. Consequently, the average outcomes if everyone were treated also varies over time. Under the assumptions discussed here, they differ only by the time trend θ_1 . We still implement our approach separately by race group, making this adjustment within each race group as well. As a result, we identify average treated outcomes separately by race and use them to estimate discrimination conditional on treated outcomes.

3.3 Measuring discrimination conditional on other functions of potential outcomes

So far, we have discussed how to estimate discrimination that is conditional on **treated** potential outcomes. However, it might be more appropriate to measure discrimination as differential treatment among individuals with the same **untreated** potential outcomes, or even the same **treatment effect**. Each of these may map to different normative notions of fairness. For example, say we wanted to study discrimination in the decision to nominate students for advanced educational programs. Expanding to condition on the treated/untreated potential outcomes and the treatment effect would allow us to understand group differences in educational program nominations between individuals who would do equally well in the program, equally well without the program and would have equal gains from the program. We next discuss how to use our approach to estimate these other discrimination estimands, and the additional assumptions that may be required, again assuming that potential outcomes are binary for simplicity.

²²This is similar to the assumption underlying the “time-corrected” Wald estimand in De Chaisemartin and D’Haultfœuille (2018). There, the treated (untreated) potential outcomes for those treated (not treated) in the pre-period are the same across group. This identifies the LATE, but does not allow us to identify the average potential outcomes of each compliance group separately. That is because their assumption pins down time trends in a) treated outcomes for always takers and b) an average of untreated outcomes for both never takers and compliers. This does not pin down time trends for compliers specifically.

Conditioning on untreated potential outcomes, $Y_i(0)$

Differential treatment among individuals with the same untreated potential outcomes is a function of period-, race- and potential outcome-specific treatment rates, as shown in Equation 7. This diverges from the treatment rates conditional on treated potential outcomes from Equation 3 in two ways. 1) The denominator is now the average outcome that would be realized if **no one was treated**. 2) The first term in the numerator, the average **untreated** outcome among those who were **treated**, is no longer directly observed in the data, since always takers are always treated.

$$E[D_i|Z = z, R_i = r, Y_i(0) = 1] = \frac{E[Y_i(0) = 1|Z = z, R_i = r, D_i = 1] \times E[D_i|Z = z, R_i = r]}{E[Y_i(0) = 1|R_i = r]} \quad (7)$$

Assumptions on the relationship between selection into treatment and average **untreated** potential outcomes, analogous to those described for treated outcomes, deal with both instances of divergence. These assumptions provide bounds or a point-estimate for the average outcomes if no one were treated, $E[Y_i(0) = y|R_i = r]$. Extrapolating $E[Y_i(0) = y|R_i = r]$ involves extrapolating the average untreated outcomes of always takers (since they are always treated) and estimating the untreated outcomes of compliers. Hence we obtain bounds/point estimates of always takers in the process, which is a component of $E[Y_i(0) = y|Z = z, R_i = r, D_i = 1]$, depending on the period. Plugging in bounds/point estimates from each of these steps into Equation 7 yields bounds/point estimates for $E[D_i|Z = z, R_i = r, Y_i(0) = y]$. These treatment rates would then be aggregated up analogous to Equation 3, to estimate group differences in treatment among those who would have identical outcomes if not treated.

Alternatively, since treatment is binary here, the **prosecution rate** conditional on outcome if dismissed is equivalent to subtracting the **dismissal rate** for those who would have that outcome if dismissed. Appendix C.4 shows this formally. Given this mapping, if one was interested in estimating discrimination conditional on untreated outcomes, an attractive natural experiment is one that generates a small share of always takers. While this discussion has focused on Z as a binary IV, Appendix C.3 discusses the assumptions required to use DiD variation to estimate average untreated outcomes.

Conditioning on treatment effects, $Y_i(1) - Y_i(0)$

Equation 8 describes treatment rates that condition directly on the treatment effect (τ_i) in a similar fashion. This object departs from Equation 3 in two ways. 1) The denominator is the share of individuals in the population who would realize a given treatment effect value. 2) The first term in the numerator is the share of treated individuals who would realize a given treatment effect value. We cannot estimate these quantities in the same way that we have done when conditioning on treated or untreated potential outcomes. This is because τ_i is never observed for any individual in the data and can take multiple values. For example, even if both $Y_i(1)$ and $Y_i(0)$ are binary, $\tau_i \in \{-1, 0, 1\}$.

$$E[D_i|Z = z, R_i = r, \tau_i = y] = \frac{E[\tau_i = y|Z = z, R_i = r, D_i = 1] \times E[D_i|Z = z, R_i = r]}{E[\tau_i = y|R_i = r]} \quad (8)$$

$$\tau_i \equiv Y_i(1) - Y_i(0)$$

Conditioning on the treatment effect requires assumptions on the support of the treatment effect. If we assume τ_i is binary, say due to some theoretical or empirical justification, we can overcome the two challenges above. For example, we may be in a context where the treatment (prosecution) is unlikely to reduce future re-offending. Such an assumption would imply that $\tau_i \in \{0, 1\}$, which in turn implies that the average treatment effect (ATE), $E[\tau_i|R_i = r]$, coincides with the denominator of Equation 8. This solves the first challenge. Similarly, $\tau_i \in \{0, 1\}$ implies that $E[\tau_i = y|Z = z, R_i = r, D_i = 1]$ is the average treatment effect on the treated (ATT). Recall that we directly observe average treated outcomes for the treated in the data and that the discussion regarding conditioning on untreated outcomes provided an estimate of the average untreated outcomes for the treated. The difference between these two averages is the ATT. Under the restriction that $\tau_i \in \{0, 1\}$, this identifies the proportion of treated individuals with a treatment effect of $\tau_i = 1$: $E[\tau_i = 1|Z = z, R_i = r, D_i = 1]$.

Plugging in bounds/point estimates from each of these steps into Equation 8 yields bounds/point estimates for $E[D_i|Z = z, R_i = r, Y_i(0) = y]$.²³ These treatment effect-specific treatment rates would then be aggregated up analogous to Equation 3, to estimate group differences in treatment among those who would have the same treatment effect, assuming binary treatment effects.

3.4 Recap: Assumptions and step-by-step guide

In this section we have discussed how to use a natural experiment to estimate discrimination between two groups, accounting for any group differences in the distribution of potential outcomes. Implementing this requires the following.²⁴

1. A natural experiment that can be mapped to an IV framework
 - If using DiD variation, need time to not shift treatment, and a parallel trends assumption for potential outcomes
2. A potential outcome, $Y_i(D_i)$, that corresponds to a notion of fairness. That is, the choice of $Y_i(D_i)$ should be such that group differences in treatment between people with the same $Y_i(D_i)$ can be interpreted as discriminatory.

²³Bounding this requires bounding a non-linear function of point identified and partially identified objects. Appendix C.4 discusses how we compute the bounds in such a case.

²⁴So far we have discussed estimating aggregate measures of discrimination. One can also use our approach to quantify decision-maker-specific discrimination estimates with large enough samples and first stages within the subsample for each decision-maker, j . Repeating our approach within each j -subsample yields estimates of the average potential outcomes in each j 's subsample, $E[Y_i(D_i)|j]$. Decision-makers with similar $E[Y_i(D_i)|j]$ observe subsamples with similar potential outcomes. j -specific discrimination estimates are comparable, in a 'selection-on-unobservables' strategy, among such a subset of decision-makers.

3. Use the natural experiment to estimate whether the underlying distribution of potential outcomes differ between the groups. For example, if $Y_i(1)$ is binary, this amounts to comparing the average outcomes if everyone of each group were treated.
4. If the potential outcomes differ by group, estimate average discrimination conditional on potential outcomes following [Equation 2](#).

We apply this approach to two empirical applications. The first studies socio-economic discrimination in student grade promotion, using a regression discontinuity approach. The second studies racial discrimination in prosecution, using a DiD approach. In both applications, we adopt the partial identification approach, since the data are inconsistent with the restrictions required for the point estimation approach. We do this by first bounding the average potential outcomes separately by group, and then plug these bounds directly into the expression for our object of interest: the average period-specific discrimination, Δ_z , in [Equation 3](#). We can also estimate bounds on the underlying group- and potential outcome-specific treatment rates, which we report in appendices.²⁵

We generate bootstrapped confidence intervals for these bounds using a Bayesian bootstrapping procedure (Rubin, 1981). We randomly draw weights from $\Gamma(1, 1)$ and use these weights to compute the moments in the estimation procedure, enforcing the weak monotonicity restriction within each re-weighted bootstrap sample. We then report the 95% percent confidence intervals for the single true underlying parameter using the resulting bootstrap distribution, following Imbens and Manski (2004).

Next, we demonstrate our approach using an RD approach, which does not require the auxiliary DiD assumptions described above, in the context of socio-economic discrimination in student grade promotion. We then use a DiD design to measure racial discrimination in prosecution decisions.

4 Socio-economic discrimination in student grade promotion

In this section we use the approach described in [Section 3](#) to measure socio-economic (SES) discrimination in the decision whether to promote or retain Michigan public school students to the next grade. This is often a key decision in students' lives that can have large academic and non-academic impacts (Jacob and Lefgren, 2004, 2009; Eren, Lovenheim, and Mocan, 2022; Hwang and Koedel, 2022). We assess if there are SES differences in potential outcomes if promoted using a 2020 state-wide introduction of a formulaic rule to determine promotion decisions. This rule generates a test score regression discontinuity (RD) design, which is useful for two reasons. 1) This highlights the pros and cons of implementing our approach with an RD approach, which has a more straightforward mapping to the instrumental variables framework, rather than a difference-in-difference

²⁵Note that one could also bound average period-specific discrimination by 1) first constructing gaps using the bounds on the group- and potential outcome-specific treatment rates, 2) computing the average, and then 3) taking the minimum and maximum. This will differ from our approach of plugging in the bounds on average potential outcomes directly into the equation for average period-specific discrimination because minimum/maximum are not linear functions. We prefer directly plugging bounds on average potential outcomes into the expression for Δ_z in [Equation 3](#) since our main goal is estimating discrimination, conditional on potential outcomes.

design. 2) Exploiting the time variation in the introduction of the rule could be confounded by various factors related to the onset of the COVID-19 pandemic. We find evidence of meaningful SES differences in the underlying chances of success if promoted. We find significant SES gaps in promotion rates, even after accounting for these SES differences in potential outcomes. Next, we discuss the introduction of the rule, the data and estimate average discrimination in promotion decisions that conditions on potential outcomes.

4.1 Natural experiment: Michigan’s ‘Read by Grade 3’ Law

In 2016, the Michigan legislature issued state-wide guidelines regarding the retention and promotion of 3rd graders in public schools (Public Act 306 of 2016). The new bill, also known as the ‘Read by Grade 3’ (RBG3) law, intended to improve public school students’ reading skills. One component of the law introduced a formulaic rule to determine when a student should be retained instead of being promoted. Prior to the bill, promotion decisions were at the discretion of the school or district staff. Now, 3rd graders who scored 1252 or lower (approximately the 5th percentile) on the Michigan standardized reading test (English Language Arts Michigan Student Test of Educational Progress or ELA M-STEP) were to be retained while the rest were to be promoted to 4th grade.²⁶ The promotion component of the RBG3 policy was meant to come into effect in the 2019-20 school year but was delayed by a year due to the COVID-19 pandemic, and eventually repealed since it was widely unpopular (Donahue, 2023; Povich, 2023). As a result, formula-based promotion and retention decisions affected students who were in 3rd grade during the 2020-21 and 2021-22 school years.

The formula-based system to decide promotion and retention for students presents an opportunity to study SES discrimination in student grade promotion decisions if the formula induced an exogenous shift in the probability of being promoted – i.e., the treatment rate – at the specified 3rd grade ELA-M-STEP cut-off score. As before, this shift is what we need to quantify whether there are differences by SES in the underlying potential outcomes of promotion. We follow the approach in Section 3, but use a regression discontinuity (RD) design to estimate discrimination between students who would have the same potential outcome. Other quasi-experimental strategies that rely on the variation in the timing of these policies, e.g., difference-in-difference, would be challenging, given how close this policy was to the start of the COVID-19 pandemic.

We use the same data as in recent work studying the impacts of multiple aspects of the RBG3 policy with an RD design at this test score cut-off. (Westall et al., 2022a,b; Berne et al., 2023; Westall, Strunk, and Utter, 2023). For each public school 3rd grader in the affected cohorts, we observe: their 3rd grade test scores, whether they were promoted to 4th grade and their performance in the following academic year (regardless of the promotion decision), as well as a host of baseline characteristics.²⁷ We include all first-time 3rd grade ELA M-STEP test-takers during the two years

²⁶The policy also required schools to provide students below the cut-off with additional interventions. Appendix A.1 discusses this further, along with other details on the policy.

²⁷We observe performance outcomes even for students retained in the 3rd grade, since they take the 3rd grade tests again in the following year.

that the formula-based retention rule was active. In our analysis sample, we only include the subset of these students who scored within 10 points of the ELA M-STEP cut-off.²⁸

Column 1 of Table 1 compares the general 3rd grade student body in the two affected cohorts to our analysis sample (Column 2). Michigan public school 3rd graders are diverse in terms of race, ethnicity and economic status. Overall, [pending disclosure] of students are non-white and [pending disclosure] of students are designated as facing some economic disadvantage.²⁹ We refer to economically-disadvantaged students as ‘low SES’ and the rest of the students as ‘high SES’.

Since our analysis sample limits to students with ELA M-STEP scores in a small window around the 5th percentile cut-off, students here are relatively more disadvantaged than the average 3rd grader in Michigan’s public schools. [pending disclosure] are economically-disadvantaged, and [pending disclosure] are non-white. Students in our analysis sample are more likely to attend a charter school, demonstrate limited English proficiency and participate in special education programming. Their baseline 3rd grade ELA M-STEP scores are lower by construction, [pending disclosure] on average (compared to [pending disclosure] among all 3rd graders). This places the average student in our sample at the lowest 3rd grade proficiency level designated by Michigan Department of Education (‘Level 1: Not proficient’).

Table 1: Characteristics of Michigan 3rd grade students

[pending disclosure]

Note: Column 1 includes all Michigan public school 3rd graders who took the ELA M-STEP for the first time in academic years 2020-21 and 2021-22. Column 2 limits to those 3rd graders who scored between [1242, 1262] on the 3rd grade ELA M-STEP.

Despite the fact that this variation has been studied and validated by prior work, we present additional validation results since we use an analysis bandwidth that is smaller than prior work. We conduct all validation tests within SES, since we need a valid RD design for each SES. Figure A1 finds no evidence of manipulation in the running variable, using the Cattaneo, Jansson, and Ma (2018) density test. Figure A2 and Figure A3 show that demographic and academic characteristics are smooth around the cut-off. Figure A4 summarizes the prior two sets of figures, showing that students around the cut-off are also similar in terms of their predicted 4th grade performance, using observables.

Next, we turn our attention to whether the policy rule actually resulted in discontinuous changes in the probability that students are promoted. If so, we can use this to estimate average potential outcomes for always takers, compliers and never takers, and use that information to estimate average outcomes if all students of both SES groups were promoted. We do this by estimating the specification in Equation 9.

²⁸We use a smaller bandwidth than other work studying RBG3 because we implement exercises that use objects estimated at the cut-off to inform discrimination away from the cut-off (but within the bandwidth). These require assumptions that are more likely to hold in a small window.

²⁹Students are designated as economically-disadvantaged in the data if the student: was eligible for free/reduced-price lunch, received SNAP/TANF, was homeless, was a migrant, or was in foster care.

$$\text{Outcome}_i = \alpha + \beta \mathbb{I}(\text{Score}_i > 1252) + \delta_1 \text{Score}_i + \delta_2 \mathbb{I}(\text{Score}_i > 1252) \times \text{Score}_i + \varepsilon_i \quad (9)$$

Figure 2 plots the relationship between the 3rd grade ELA M-STEP and the probability of being promoted, along with the estimated β from Equation 9, separately for high and low SES. We see meaningful changes in the probability of being promoted around the cut-off for both groups of students. High SES students just above the cut-off are [pending disclosure] more likely to be promoted than high SES students below the cut-off. Low SES students just above the cut-off are [pending disclosure] more likely to be promoted than their counterparts below the cut-off.

Figure 2: Impact of test score cut-off on promotion rates

[pending disclosure]

Note: Each Panel presents RD estimates investigating the impact of the RBG3 test score-based promotion policy on promotion rates, using a local linear specification. The x-axis represents the running variable, the 3rd grade ELA M-STEP, re-centred by the cut-off of 1252. The sample includes students who took the 3rd grade ELA M-STEP for the first time between 2020 and 2022 and scored within 10 points of the cut-off. ‘RD estimate’ presents β from Equation 9. Standard errors are clustered at the level of the running variable.

Notably, while the RBG3 law stipulated a formulaic approach to promotion and retention policy, these figures suggest that a large amount of discretion was still used in making promotion decisions, consistent with prior work studying the law’s implementation (Westall et al., 2022a,b). Instead of seeing promotion shares jump from zero below the cut-off to one above the cut-off, we see modest but meaningful shifts. This “fuzzy” RD is due to a section of the law that allowed students below the cut-off (who should have been retained according to the law) to be promoted if they met specific criteria.³⁰ However, despite how common these exemptions seem to be, the test score cut-off still caused a meaningful share of students who would have otherwise been retained to be promoted.

4.2 Using the RBG3 RD to estimate discrimination in student grade promotion

We start by mapping the objects in the empirical discussion to the potential outcomes framework in Section 3. Students are considered treated if they are promoted to 4th grade for the upcoming school year ($D_i = 1$) and ‘untreated’ if retained in 3rd grade. The treated potential outcome is $Y_i(1)$, how well a student would perform if promoted to the next grade for the upcoming school year. For students who are retained, we do not observe how well they do in the 4th grade, since they are still in the 3rd grade.³¹ As a result, we do not observe $Y_i(0)$.

The instrument Z , is an indicator for being above or below the RD cut-off (we discuss complications due to the local nature of the RD below) and we use the RD to assess if there are SES differences in how ready students are for the 4th grade. If so, we adjust for such SES differences

³⁰Common exemptions include students who: are English language learners, have disabilities, and whose parents submit an exemption request. See Appendix A.1 for additional details.

³¹Admittedly, these students will eventually reach the 4th grade, but their outcomes at that point will be a function of being retained as well as being older for their grade. Our focus is on the upcoming school year and we do not observe outcomes in 4th grade in the upcoming school year for retained students.

following Section 3, and estimate SES differences in promotion for students who would have performed equally-well if promoted. We define whether students are high or low SES by whether they are flagged as being economically-disadvantaged, and denote this by $R_i \in \{h, l\}$.

We construct our empirical analog of $Y_i(1)$ using students’ test scores in the next school year, if they are promoted. Since Michigan public school students in 4th grade are required to undergo standardized testing, we observe an objective measure of student performance among the promoted students when they take the 4th grade test. This has a direct mapping to fairness norms – between two students equally likely to do well in 4th grade, it would be unfair to promote one student and not the other. This also maps well to the underlying decision problem followed by teachers and other education staff. In fact, there were concerns that some students were advancing to 4th grade without the skills to cope. The reform was conceived to improve skills that educators viewed as key inputs to students’ success in later grades (French, 2019; Povich, 2023). This anecdotal evidence suggests that around this time period, teachers and other school authorities ideally wished to only promote students who were ready for the next grade.

We define $Y_i(1) = 1$ if a student demonstrates “any proficiency” in both the Math and ELA M-STEP tests in the 4th grade, if promoted. A student is considered to demonstrate “any proficiency” if they receive a score of Level 2 or above according to the Department of Education guidelines in Table A1. We consider this binary outcome to be a proxy for whether a promoted student was ready for the 4th grade. Returning to the potential outcomes framework, this means that $Y_i(1) = 1$ if a student is ready for 4th grade and $Y_i(1) = 0$ if a student is not ready.³²

As before, we use quasi-experimental variation in promoted outcomes to estimate how average promoted outcomes varies across always takers, compliers and never takers. We use that information to bound the average test score outcomes if everyone in the analysis sample were to be promoted. Figure 3 plots the relationship between the 3rd grade ELA M-STEP score and 4th grade outcomes but limits the sample to only students who were promoted, since we are trying to understand how promoted outcomes vary around the cut-off. Marginal high SES students who are promoted due to the RBG3 policy are [pending disclosure] less likely to be proficient in 4th grade than promoted students below the cut-off. Marginal low SES students are [pending disclosure] less likely to be proficient in the 4th grade than promoted students below the cut-off.

Figure 3: Impact of test score cut-off on 4th grade outcomes (Only promoted students)

[pending disclosure]

Note: Each Panel presents RD estimates investigating the impact of the RBG3 test score-based promotion policy on 4th grade proficiency rates, using a local linear specification. ‘Share proficient’ represents the share of individuals who demonstrated any proficiency on both the Math and ELA M-STEP in 4th grade, as defined in Table A1. The x-axis represents the running variable, the 3rd grade ELA M-STEP, re-centred by the cut-off of 1252. The sample only includes students who were promoted to 4th grade and took the 3rd grade ELA M-STEP for the first time between 2020 and 2022 and scored within 10 points of the cut-off. ‘RD estimate’ presents β from Equation 9. The p -value in the second line is a one-sided test of whether the ‘RD estimate’ is weakly positive. Standard errors are clustered at the level of the running variable.

³²We focus on a binary proficiency measure since our sample consists of students with 3rd grade ELA M-STEP scores around the 5th percentile of the score distribution. As a result, most of the variation in outcomes is likely to come in the Level 1 and Level 2 region, and binarizing as we do preserves power.

In an RD setting, the proportions and outcomes of always takers, never takers and compliers are identified by the intercepts of the local linear lines of best fit at the cut-off. Here, the proportion of always takers is the y-intercept in Figure 2 as the line approaches the cut-off from below zero. The proportion of compliers is the difference between the y-intercept in Figure 2 as the line approaches the cut-off from above zero and the proportion of always takers. Never takers are the remaining share of the relevant population. Similarly, the treated outcomes of always takers is the y-intercept in Figure 3 as the line approaches the cut-off from below zero. The treated outcomes of always takers and compliers together is the y-intercept in Figure 3 as the line approaches the cut-off from above zero. As described in Section 3, this is the information we need to estimate the average promoted outcomes for compliers, and bound average outcomes for never takers. Combining the estimates of average promoted outcomes for always takers, compliers and never takers for each SES group, we have the information to bound the average promoted outcomes if everyone from both SES groups were to be promoted. This identifies average promoted outcomes at the cut-off, and not necessarily away from it.

Before presenting our SES-specific estimates of average outcomes if everyone were promoted, we first address the fact that the estimated discontinuities in outcomes if promoted are imprecise and large relative to the first stage.³³ To mitigate the effects of potential noise on our estimated bounds of the average outcome if all students were promoted, we adjust the bounding approach described in Section 3 to only use the sign of the discontinuity, rather than the magnitude. Given that Figure 3 implies that, for both SES groups, always takers for promotion more likely to be proficient in 4th grade than compliers, the approach in Section 3 involves assuming that never takers' proficiency rate if promoted is bounded above by that of compliers and below by zero. We modify this to assume that the average proficiency rate for both **compliers and never takers** together is bounded above by that of always takers, and below by zero.³⁴ Under this adjustment, we still assume weak monotonicity of the relationship between the treated outcomes and treatment propensity, using the estimated direction of the relationship between treated outcomes for always takers and compliers. The p -values presented in each Panel of Figure 3 suggest that our estimate of the sign of the relationship is credible – in both cases we reject the null that the relationship is weakly positive.³⁵

³³The discontinuity estimates might also be biased by other treatments potentially shifting around the cut-off. The policy mandated that students below the cut-off receive additional interventions and encouraged (but did not mandate) this for students above the cut-off. As a result, students could be shifted between multiple treatments (not just promotion and retention) around the cut-off. Appendix A.1 discusses the conditions under which this would bias our analysis, and discusses existing evidence that suggests such bias is small.

³⁴Figure A6 displays the resulting estimates of average outcomes if promoted by compliance group and SES. Compliers and never takers, the portion of the population whose treated outcomes we bound, make up [pending disclosure] and [pending disclosure] of the population of low and high SES students respectively.

³⁵Figure A5 presents the results of an additional test validating the sign of the discontinuity in treated outcomes. We conduct a placebo exercise that re-estimates the RD estimates in Figure 3, using every other possible test score cut-off in our analysis sample, while keeping the bandwidth the same. Each panel displays the distribution of resulting placebo RD estimates, and the vertical lines plot the observed estimates shown in Figure 3. Only [pending disclosure] of placebo estimates for the low SES sample are larger than the one we observe, while this is true for [pending disclosure] of the high SES placebo estimates.

Figure 4: Average outcomes if promoted, $E[Y_i(1)|R_i = r]$

[pending disclosure]

Note: This figure presents bounds on the average treated outcome obtained using the approach described in Section 3. The treatment is promotion and the treated outcome is whether a student demonstrated any proficiency on both the Math and ELA M-STEP in 4th grade, as defined in Table A1. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap. The p -value is from a formal bootstrapped test of whether the identified sets overlap, described in Appendix C.5.

With these adjustments, Figure 4 shows that there are indeed large SES differences in the underlying 4th grade outcomes that would be realized if all students in the analysis sample were promoted. [pending disclosure] of high SES students would do well if promoted to 4th grade, while this is true for only [pending disclosure] of low SES students. Using a bootstrapped inference procedure described in Appendix C.5, we reject the null that these bounds overlap ($p =$ [pending disclosure]). Given that there are meaningful cross-SES differences in the underlying readiness for 4th grade, the raw SES gap in promotion is likely biased.

We now estimate bounds on the SES differences in promotion rates that condition on having the same outcome if promoted. Since each of the average outcomes if promoted in Figure 4 is estimated only at the cut-off, we will only use the average outcomes of promoted students **at the cut-off** and the promotion rate of students **at the cut-off** when following Equation 3. Such estimates are informative of SES discrimination in promotion rates **at the cut-off**.

However, we can estimate discrimination both below the cut-off but within the sample window under two additional assumptions. First, we need to assume that the running variable alone does not influence promotion rates. Columns 1 and 3 of Table A2 test this, failing to reject that promotion status varies with 3rd grade ELA M-STEP scores for either SES group in our analysis sample, which provides suggestive evidence for this assumption. Second, we need to assume that the average outcome if everyone at the cut-off were promoted is the same as the average outcome if everyone above or below the cut-off were promoted. This assumption is less likely to be satisfied – columns 2 and 4 of Table A2 show that promoted outcomes clearly increase with the running variable.³⁶ The sign of the resulting bias on the discrimination estimands is ambiguous, as discussed in detail in Appendix C.6. Given these issues, we focus on estimates of SES discrimination in promotion **at the cut-off**, but present estimates for students below the cut-off as well since it is arguably more policy-relevant than evidence that is only applicable at the test score cut-off.

Figure 5 presents our estimates of the high–low SES differences in promotion rates under the different assumptions. The first set of bounds (in maroon) shows that at the cut-off, high SES students are [pending disclosure] more likely to be promoted relative to low SES students, even after accounting for SES differences in how prepared students are for the 4th grade. The next two sets of bounds (in blue) provide more expansive measures of discrimination, under the assumptions described above. High SES students below the cut-off are [pending disclosure] more likely to be

³⁶These assumptions are stronger than those in typical approaches to extrapolate away from RD cut-offs. This is because the focus here is on extrapolating average potential outcomes rather than treatment effects (Angrist and Rokkanen, 2015; Cattaneo et al., 2021; Ricks, 2022).

Figure 5: SES differences in promotion, conditional on promoted outcome (Δ_z)

[pending disclosure]

Note: This figure presents bounds on the average discrimination in promotion rates, conditional on treated potential outcomes, using the approach described in Section 3. The treatment is promotion and the treated outcome, denoted by $Y_i(1)$, is whether a student demonstrated any proficiency on both the Math and ELA M-STEP in 4th grade, as defined in Table A1. Estimates below the cut-off are computed by applying estimates of the average treated outcomes to all students below the cut-off, which is valid under assumptions described in Appendix C.6. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

promoted than their low SES counterparts, even after accounting for unobservable differences.^{37,38}

Our results make clear that the promotion disparities documented in recent work on the RBG3 law are not solely driven by differences in underlying unobservables (Westall et al., 2022a,b).

Overall, our analysis suggests that despite the intended formulaic nature of the RBG3 policy rules, the discretion that decision-makers in this context exercised resulted in meaningful unwarranted disparities in promotion decisions by SES. Our analysis also suggests that these gaps are concentrated among students who are not ready for 4th grade. The estimates of SES disparities in promotion rates that we present here are quite different from alternative approaches. ‘Selection-on-observables’ approaches would have estimated that the disparity at the cut-off was [pending disclosure] smaller than the one that we find.

5 Racial discrimination in misdemeanor prosecution

In this section we use the approach described in Section 3 to measure racial discrimination in the decision to prosecute misdemeanor defendants in King County, Washington. This is a key decision in individuals’ lives that can have large future consequences (Leasure, 2019; Mueller-Smith and Schnepel, 2021; Agan, Doleac, and Harvey, 2023). We find evidence that average outcomes if prosecuted differ by race, using difference-in-difference variation to isolate the quasi-experimental effects of a cut to prosecutors’ budget. Accounting for these racial differences in potential outcomes, we find that even though prosecution rates fell overall, white defendants were more likely to be prosecuted than minority defendants after the reform. We find suggestive evidence that this is driven by prosecutors dropping low quality and resource-intensive cases. We also discuss robustness to conditioning on outcomes if dismissed, and to changing definitions of samples and key variables. Next, we discuss institutional details on King County, validate the natural experiment generated by the budget reform, and estimate average discrimination in prosecution that conditions on potential

³⁷We rule out that these gaps are driven by SES differences in how likely parents are to request retention exemptions for their children (see Appendix A.1 for details on exemptions). We observe similar patterns in SES differences in average promoted outcomes (Figure A7) and SES differences in promotion rates that condition on these differences (Figure A8) if we exclude students whose parents requested that they be promoted instead of being retained.

³⁸Disaggregating gaps from Figure 5 into promotion rates for students at the cut-off who would and would not be ready for 4th grade if promoted suggests that the SES gaps we find are driven by students who are not ready for the 4th grade (see Figure A9). Figure A9 also suggests that promotion rates for students who would be ready for 4th grade are weakly higher than that for students who would not be, consistent with school decision-makers targeting promotion towards students who are ready for the 4th grade.

outcomes.

5.1 Natural experiment: King County budget reform

We use our approach to study racial discrimination in misdemeanor prosecution in King County, Washington (Seattle metropolitan area + suburban areas). We do this using administrative records on all criminal cases from 2000–2022 from the Washington Administrative Office of the Courts. We consider an individual as having their case prosecuted if their case **did not** meet the following condition: dismissed without requiring any punishments. Our primary definition of a punishment excludes fines, but we assess robustness to including them. Our sample consists only of individuals in the court records, and so all of our estimates are representative of individuals who have been arrested and whose cases have been accepted by the prosecutors’ office. This is not representative of the larger group of individuals who have contact with the Washington criminal legal systems.

We focus on racial discrimination in prosecution between white (non-Hispanic) and ‘minority’ defendants. This comparison is motivated by the fact that the population that has contact with the Washington criminal legal system is quite diverse. A large proportion of this ‘minority’ group includes individuals of Native Hawaiian and Pacific Islander descent, who often face disadvantage of various forms and are over-represented in the criminal legal system in the Western United States (Hu and Esthappan, 2017; Malott, 2024). Nevertheless, we demonstrate that our results are robust to comparing prosecution rates white (non-Hispanic) versus Black and Hispanic defendants.

As discussed in Section 3, we need a natural experiment that shifts prosecution rates to estimate if unobserved potential outcomes vary by race, and then estimate discrimination conditional on the unobserved potential outcomes. We use the fact that in September 2010, King County announced that the Prosecutor’s Office budget would be cut by around 9%, in response to large budget deficits. This unanticipated cut led to considerable public discussion of how to cope with the new budget realities (Constantine, 2010). The Prosecutor’s Office publicly discussed the prospect of laying off many of its employees and focusing their resources on pursuing offences they deemed to be high-priority (Ervin, 2010).

The circumstances created by the budget reform present an opportunity to use our approach to study racial discrimination in prosecution. The sharp contraction to prosecutorial resources should result in many cases being dropped. A shift in prosecution rates would let us partition the population into always takers, compliers and never takers for prosecution. We would then examine how outcomes if prosecuted vary across these groups, and then account for any differences.

We isolate the quasi-experimental variation using a difference-in-difference strategy that compares changes in prosecution and recidivism rates around the budget reform in King County, relative to adjacent counties that were unaffected by the reform.³⁹ We construct our analysis sample using criminal cases filed in the relevant counties’ District Courts, which hear misdemeanor cases, between October 2008 and September 2012. We limit to cases from the District Courts since these courts are funded by counties and are hence most likely to be affected by this county budget reform.

³⁹The adjacent counties include: Snohomish, Pierce, Kitsap, Kittitas and Chelan.

However, we use information on cases filed in other Washington courts, including felony charges (filed in Superior Courts) to construct re-offence outcomes and measure criminal history. These variables are not limited to the October 2008 and September 2012 interval. If an individual has cases filed on multiple dates within this time frame, we only include the first case, to ensure that the probability of multiple appearances is not a function of prosecution decision

The final sample, described in [Table 2](#), consists of around 120,000 unique cases. 30% of the sample consists of non-white defendants, and this group is quite diverse – 43% are Black, 32% are Hispanic and 18% are Asian American or Pacific Islander (AAPI). We refer to the group of non-white defendants as ‘minority’ defendants. Women make up almost a quarter of the sample, and the sample consists of a wide range of individuals in terms of age and criminal background. The average defendant is almost 35 years old, and 47% of individuals have had at least 1 conviction in the past (averaging 3.5 prior convictions). Prosecution rates are quite high, but individuals are unlikely to face jail time if they prosecuted. Only 9% of individuals prosecuted in King County (and 6% overall) in our sample served any jail time. Among those who serve any time in jail, the average sentence is around 40 days long.

Table 2: Characteristics of Washington District Court sample

	Overall	King County	Adjacent Counties
<i>N</i>	122,156	51,242	70,914
Demographics			
White (Non-Hispanic)	0.72	0.65	0.78
Black	0.12	0.16	0.09
Hispanic	0.09	0.09	0.09
AAPI	0.05	0.08	0.03
Age at disposition	34.6	34.8	34.4
Male	0.74	0.73	0.74
Criminal history			
Any prior convictions	0.47	0.42	0.50
# prior Any	3.8	3.5	3.9
Case outcomes			
Case prosecuted	0.86	0.82	0.88
White	0.86	0.83	0.87
Minority	0.85	0.81	0.89
Jail sentence Prosecuted	0.06	0.09	0.05
Sentence length (Days) Jail sentence	40.4	39.6	41.3

Note: Sample includes all criminal cases disposed in the District Courts in Chelan, King, Kitsap, Kittitas, Pierce and Snohomish counties in Washington State between October 2008 and September 2012. For defendants with multiple dispositions in this time frame, we include only the first case. “AAPI” stands for Asian American or Pacific Islander.

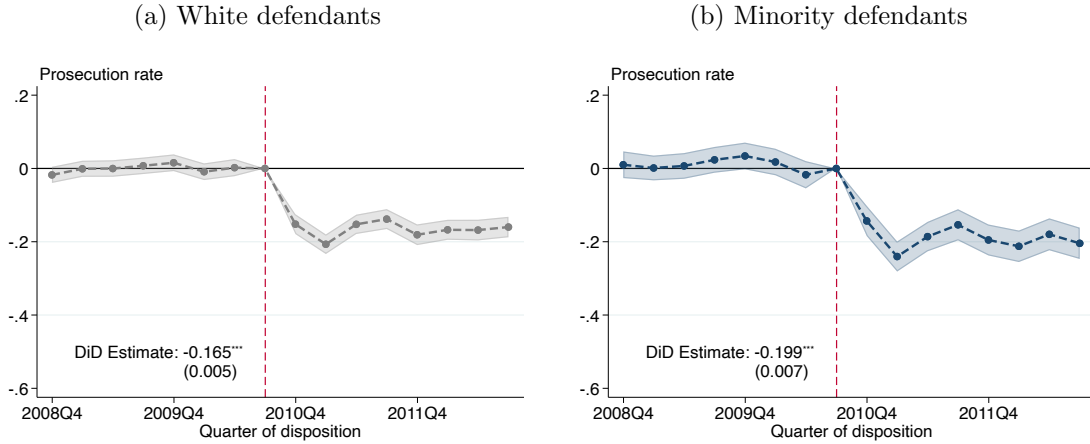
We first compare the changes in prosecution rates before and after the King County budget reform to changes in prosecution rates in adjacent counties that were unaffected by the budget reform. This involves estimating the specification in [Equation 10](#), where D_{itg} denotes whether defendant i was prosecuted in quarter t and g denotes whether the case was disposed in King County or the adjacent counties. We investigate this separately for white and minority defendants to ensure that we have enough variation in prosecution rates in each racial subgroup.

[Figure 6](#) documents large drops in prosecution rates due to the King County budget reforms. Prosecution rates fall by 16.5pp and 19.9pp for white and minority defendants respectively (17.8%

and 21.7% of pre-reform average prosecution rates in King County).⁴⁰ We do not see any evidence of pre-trends in prosecution rates, which provides some evidence that this natural experiment is credible (we discuss additional validity tests below). The magnitude of these shifts in prosecution rates pin down the complier share of white and minority defendants. Given the overall high rate of prosecution, these shifts in prosecution suggest that we will have to bound outcomes for a relatively small share of the population.

$$D_{igt} = \theta_t + \delta \mathbb{I}[\text{King County}] + \sum_{k \neq -1} \beta_k (\mathbb{I}[t - \text{Budget Reform} = k] \times \mathbb{I}[\text{King County}]) + \varepsilon_{igt} \quad (10)$$

Figure 6: Impact of King County budget reform on prosecution rates



Note: Each Panel presents event study estimates investigating the impact of the King County budget reform. Sample includes all misdemeanor defendants as described in Table 2. ‘DiD Estimate’ pools the coefficients on relative time indicators and estimates $D_{igt} = \alpha + \delta_1 \mathbb{I}[\text{King County}] + \delta_2 Post_i + \beta^{DD} \mathbb{I}[\text{King County}] \times Post_i + \epsilon_{igt}$, where $Post_i = 1$ if the case is disposed of on or after September 28, 2010, when the budget reform was announced. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

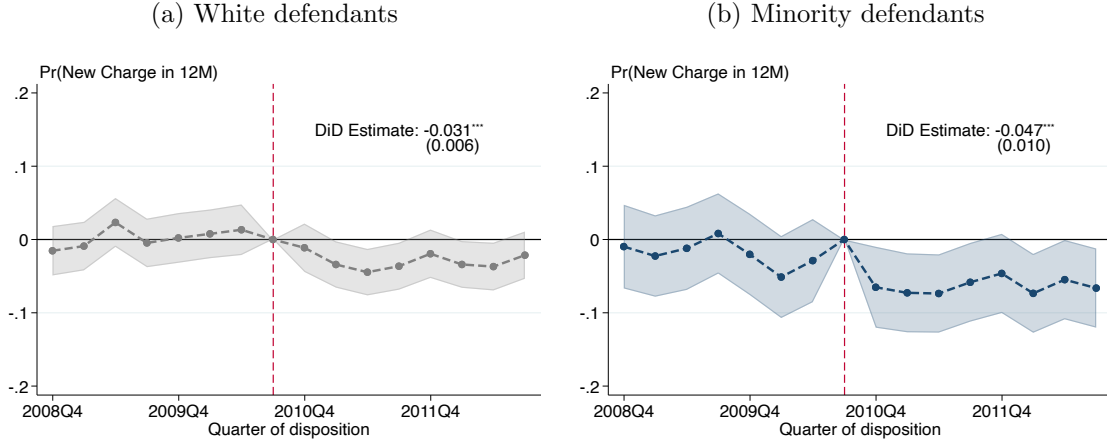
We next examine whether these shifts in prosecution rates influenced individuals’ outcomes, which will reduce the width of the bounds for never takers’ prosecuted outcomes. Figure 7 repeats the event study approach, assessing the impact of the budget reform on the probability that a defendant is charged with a new offence one year after disposition. We see that not being prosecuted reduces one year re-offence rates by 3.1pp for white defendants and 4.7pp for minority defendants (13.1% and 15% of pre-reform average re-offence rates in King County). Again, we see no evidence of pre-trends in re-offence rates.⁴¹ The direction and magnitude of these estimates are consistent

⁴⁰Figure B5 shows that the reduction in prosecution due to the reform is robust to using a more expansive definition of prosecution that considers cases listed as ‘Dismissed’ but with fines or fees as “prosecution”. Using that definition, we see that prosecution falls by 15.9 p.p. and 18.8 p.p. for white and minority defendants, which is very similar to what we see with our main definition.

⁴¹These reductions are unlikely to be driven by incapacitation, given that only 9% of prosecuted defendants in King County served jail sentences. Among those who served jail sentences, the average length was 40 days, much shorter than the one year horizon used to compute the outcome (see Table 2). Finally, while the maximum possible

with recent work demonstrating that avoiding prosecution reduces future criminal activity (Mueller-Smith and Schnepel, 2021; Agan, Doleac, and Harvey, 2023).^{42,43}

Figure 7: Impact of King County budget reform on new offences over 12M



Note: Each Panel presents event study estimates investigating the impact of the King County budget reform. The re-offence outcome includes any misdemeanor or felony charges filed against an individual anywhere in Washington State. Sample includes all misdemeanor defendants as described in Table 2. ‘DiD Estimate’ pools the coefficients on relative time indicators and estimates $Y_{igt} = \alpha + \delta_1 \mathbb{I}[\text{King County}] + \delta_2 Post_i + \beta^{DD} \mathbb{I}[\text{King County}] \times Post_i + \epsilon_{igt}$, where $Post_i = 1$ if the case is disposed of on or after September 28, 2010, when the budget reform was announced. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

Next, we rule out different threats to the natural experiment’s validity. We should be concerned if there are any concurrent policy or behavioral changes that could influence the determinants of crime and confound our estimates of the budget reform’s effects. These might occur if other aspects of King County institutions, e.g., police, social services, were affected by the budget reform, or if prosecutors altered their behavior in ways other than prosecuting fewer cases. We assess how likely these concerns are through multiple exercises.

First, we test whether the composition of cases that prosecutors choose to accept from law enforcement changes discontinuously when the budget reform was enacted. We estimate a series of DiD regressions, where we compare the change in the share of individuals with a given baseline covariate before versus after the reform in King County to that same change in the adjacent counties. Figure 8 presents each of these coefficients and shows no evidence of compositional shifts in terms of most baseline characteristics (Figure B1 presents the underlying event study patterns for each covariate). We see some evidence that individuals whose cases were accepted after the reform were

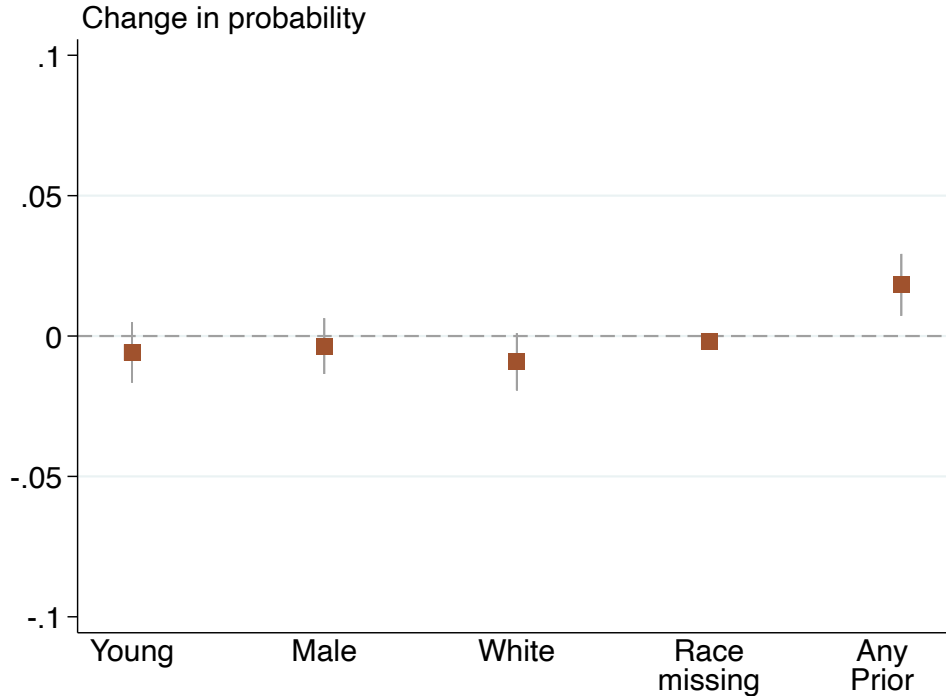
jail sentence for a misdemeanor in King County is one year, this occurs in only 6% of cases with some jail time, which represents 0.5% of prosecuted cases. As a result, potential outcomes will not be mechanically censored by jail spells.

⁴²We also find that these impacts are stable over time and still persist after two years (results pending disclosure).

⁴³These reduced form estimates are not driven by prosecutors systematically changing what cases they accept from law enforcement, e.g., by refusing all low priority cases. Figure B3 presents results from an alternative specification that excludes charges for offences commonly dropped right after the budget reform announcement (resisting arrest, criminal trespass, driving with a suspended licence, minor marijuana possession, reckless driving and DUI). Assuming this contains information about charges that the prosecutor’s office considers low-priority, we designate other charges as ‘high-priority’. We see reductions in the probability of being charged with a new ‘high-priority’ offence that are similar to our baseline estimates in terms of their proportion of the relevant pre-reform means.

1.8 p.p. more likely to have been previously charged with an offence but this is a small shift in composition (3.5% of the pre-period mean in King County).⁴⁴

Figure 8: Impact of King County budget reform on new offences over 12M



Note: Each estimate is β^{DD} from $Y_{igt} = \alpha + \delta_1 \mathbb{I}[\text{King County}] + \delta_2 \text{Post}_i + \beta^{DD} \mathbb{I}[\text{King County}] \times \text{Post}_i + \epsilon_{igt}$, where $\text{Post}_i = 1$ if the case is filed on or after September 28, 2010, when the budget reform was announced. ‘Young’ defendants are those who ≤ 28 years old at disposition and ‘Any Prior’ is an indicator for whether an individual has ever been previously charged with an offence in Washington State. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

Finally, we directly test whether law enforcement agencies in King County were laid off, reduced their arrest effort (perhaps in anticipation that prosecutors would not prosecute certain cases after the reform) or whether the reform affected other economic determinants of crime. [Figure B6](#) & [Figure B7](#) show no significant reductions in either officer employment or different categories of arrests. [Figure B8](#) similarly finds no differential changes in house prices, unemployment rates or population, suggesting that the reform did not impact other economic factors that might influence criminal behaviour.

The results of these exercises suggest that the drop in prosecution rates and resulting reduction in recidivism are driven by the unanticipated budget reform, and not by concurrent policy or behavioral changes. While the King County budget reform is a valid natural experiment, we need

⁴⁴This minor compositional shift might be due to the end of the federal investigation into Seattle Police Department (SPD) that resulted in lower SPD stops and arrests. This could have contributed to this compositional shift if police focused on more serious offences (Campbell, 2023). Campbell (2023) finds the largest reductions in SPD activity after the investigation ended (December, 2011), which corresponds to when we see changes in defendants with a prior charge (see Panel c) of [Figure B1](#)). Our first stage and reduced form estimates are nearly identical if we exclude this time period from our sample (see [Figure B2](#)), and so we proceed with the full sample for our baseline analysis.

to make the adjustments described in Section 3 to accommodate the DiD variation and use the reform to estimate discrimination. Next, we describe the adjustment and associated assumptions in the context of this setting. We then use this natural experiment to estimate racial differences in prosecution among individuals who would have the same outcomes if prosecuted.

5.2 Estimating discrimination in prosecution using the budget reform

We begin by mapping the objects in the empirical discussion to the potential outcomes framework discussed in Section 3. Individuals are considered ‘treated’ if they are prosecuted ($D_i = 1$) and considered ‘untreated’ if dismissed. Potential outcomes in each treatment state are the binary indicators of recidivism used in the event study estimates in Figure 7. That is, $Y_{it}(d) = 1$ if an individual assigned to treatment state $D_i = d$ would be charged with a new offence in Washington State within one year of disposition. Z indicates periods around the King County budget reform. Next, we validate the adjustment requires to use the budget reform DiD to estimate discrimination, and then apply our approach to estimate racial discrimination in prosecution among individuals who would have the same re-offence outcome if prosecuted. We then discuss estimating discrimination conditional on having the same re-offence outcome if dismissed.

5.2.1 Validating difference-in-difference adjustments

As described in Section 3, the first step is to use the quasi-experimental variation from the budget reform to estimate the average re-offence outcome that we would see if all defendants of each race were prosecuted. This would help us understand whether the unobserved potential outcomes vary by race, in which case we need to adjust for them. We use the trend in outcomes among prosecuted individuals adjacent counties as an estimate of the time trend that prosecuted individuals in King County would have experienced had the budget reform not occurred. Using this, we purge the change we observe in King County of the change only due to time.

In this context, this requires assuming that the following conditions hold within each race group, absent the budget reform:

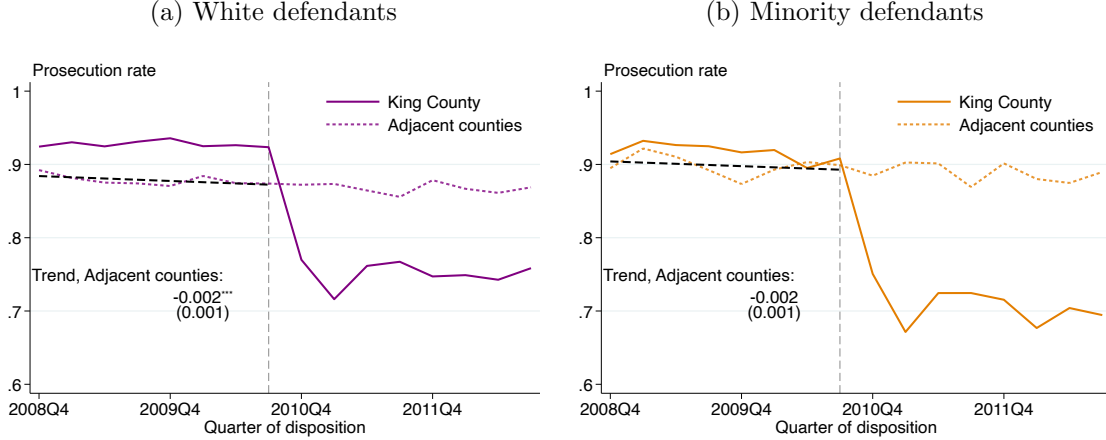
A1 Time does not shift individuals’ prosecution status

A2 Re-offence outcomes if prosecuted, $Y_{it}(1)$, trend similarly for always takers & compliers and is independent of county

While these assumptions are fundamentally untestable, we provide evidence that they are not grossly violated here. Figure 9 examines **A1**, testing for time trends in prosecution using pre-period data from the adjacent counties, separately for white and minority defendants. These shifts in prosecution rates are very small – even though estimated trend for white defendants is significant, it represents a 0.2 p.p. reduction in prosecution rates every quarter, which is approximately 1% of the reductions in prosecution that we see in Figure 6. To ensure that these aggregate trends are not masking shifts into and out of prosecution for different types of people, we repeat this exercise

separately by covariate subgroups (gender, criminal history, age). Figure B17 shows that trends in prosecution rates are similarly very small even within these subgroups. This builds confidence that individuals are not shifting into or out of treatment over time.

Figure 9: Testing trends in prosecution rates in adjacent counties



Note: The displayed coefficients are from estimating a linear regression of prosecution on a linear quarterly trend using pre-period data in the counties adjacent to King County. Standard errors on pre-period trends estimates are heteroscedasticity-robust.

Next, we test **A2**, which requires parallel trends to hold between always takers and compliers. This is because we need to account for time trends in the average prosecuted outcomes for compliers and always takers so we can use that information to construct bounds for never takers. Since we cannot identify always takers and compliers in the adjacent counties, we test for differential pre-trends by subgroup (gender, criminal history, age), which might be correlated with being an always taker or complier. Using pre-period data, Figure B18 shows that there is no evidence of differential trends in $Y_{it}(1)$ across counties within the various subgroups. Figure B19 conducts a similar exercise, finding limited evidence of differential trends in $Y_{it}(1)$ within counties but across subgroups. While this is not definitive evidence that these assumptions are satisfied, they build credibility that they are reasonable in this setting.

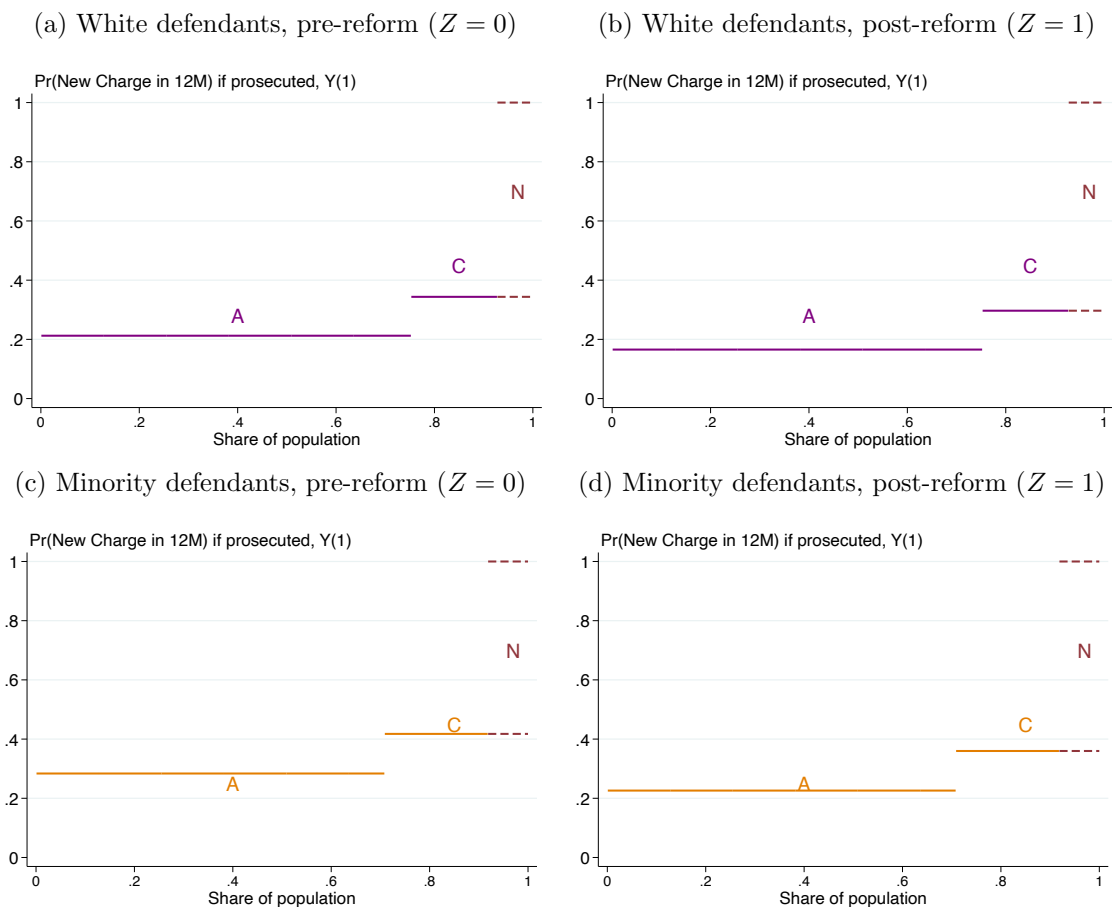
5.2.2 Discrimination results

We now use the variation from the budget reform DiD to 1) estimate if there are racial differences in the average re-offence outcome that we would see if all defendants of each race were prosecuted and 2) account for any such differences. We denote Z as indicating periods around the King County budget reform. Since Y_{it} varies with time, we estimate average prosecuted outcomes in each period t : $E[Y_{it}(1)|R_i = r]$. Figure B4 presents event study estimates showing how the reform impacts prosecuted outcomes – we use this shift in prosecuted outcomes to estimate average prosecuted outcomes for always takers and compliers.

Figure 10 displays how average outcomes if prosecuted vary across always takers, compliers and never takers for white and minority defendants. Panels a) and c) present estimates from before the

reform, and Panels b) and d) present estimates from after the reform. White defendants' average outcomes for always takers and compliers are uniformly lower than the corresponding averages for minority defendants. This suggests that there likely are racial differences in the average re-offence outcomes that we would see if all defendants were prosecuted. Additionally, we see that never takers, comprise 7-8% of the population of each race group. This implies that we have to bound outcomes for a relatively small portion of the population. As a result, the estimated bounds on the average outcomes if everyone were prosecuted are likely to be relatively tight. Since the bounds on the average outcomes if everyone were prosecuted are inputs into estimating the discrimination estimands (see Equation 3), we should expect relatively tight bounds on discrimination as well.

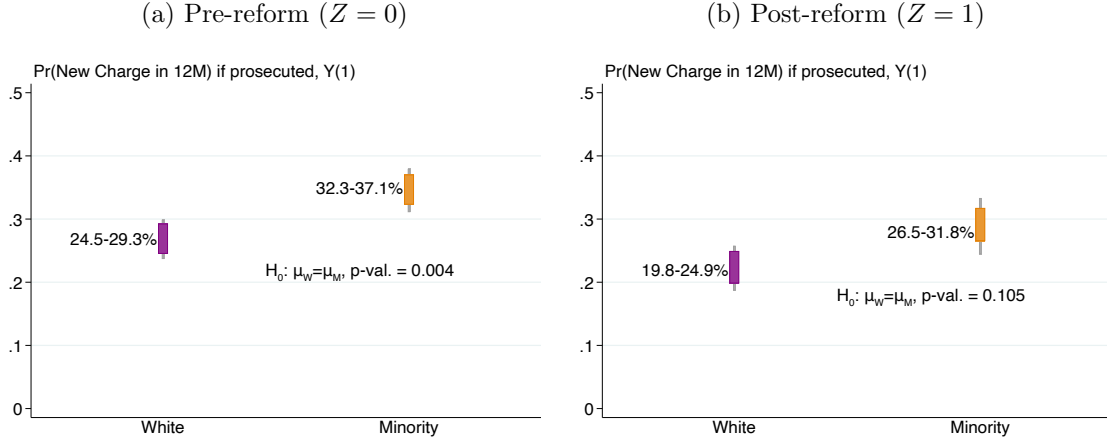
Figure 10: Average outcomes if prosecuted ($Y_i(1)$) by compliance group



Note: This figure shows the average treated outcomes for always takers ('AT'), compliers ('CT') and never takers ('NT') for each time period. The treatment is prosecution and the treated outcome is whether an individual is charged with a new offence 12M after disposition, if prosecuted. The bounds for the treated outcomes for never takers come from the assumption of weak monotonicity of the relationship between treated outcomes and treatment propensities, and that $Y_i(1) \in \{0, 1\}$.

Figure 11 aggregates the average outcomes for always takers and compliers, as well as the bounds for outcomes of never takers from Figure 10. We see meaningful and significant cross-race differences in the average outcomes that would be realized if all defendants were prosecuted. Before the budget reform, 25–29% of white defendants would have re-offended if prosecuted, while

Figure 11: Average outcomes if prosecuted, $E[Y_{it}(1)|R_i = r]$



Note: This figure presents bounds on the average treated outcome obtained using the approach described in Section 3, separately by race and time period. The treatment is prosecution and the treated outcome is whether an individual is charged with a new offence 12M after disposition, if prosecuted. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap. The p-value is from a formal bootstrapped test of whether the identified sets overlap, described in Appendix C.5.

32–37% of minority defendants would have done so. Using a bootstrapped inference procedure described in Appendix C.5, we reject the null that these bounds overlap ($p = 0.004$). After the reform, the bounds on average prosecuted outcomes are still meaningfully different (20–25% vs 27–32%), although testing the probability that they overlap is less precise ($p = 0.105$).⁴⁵ Given that outcomes if prosecuted differ meaningfully by racial group, not accounting for unobservable cross-race differences in this setting would lead to incorrect estimates of discrimination.

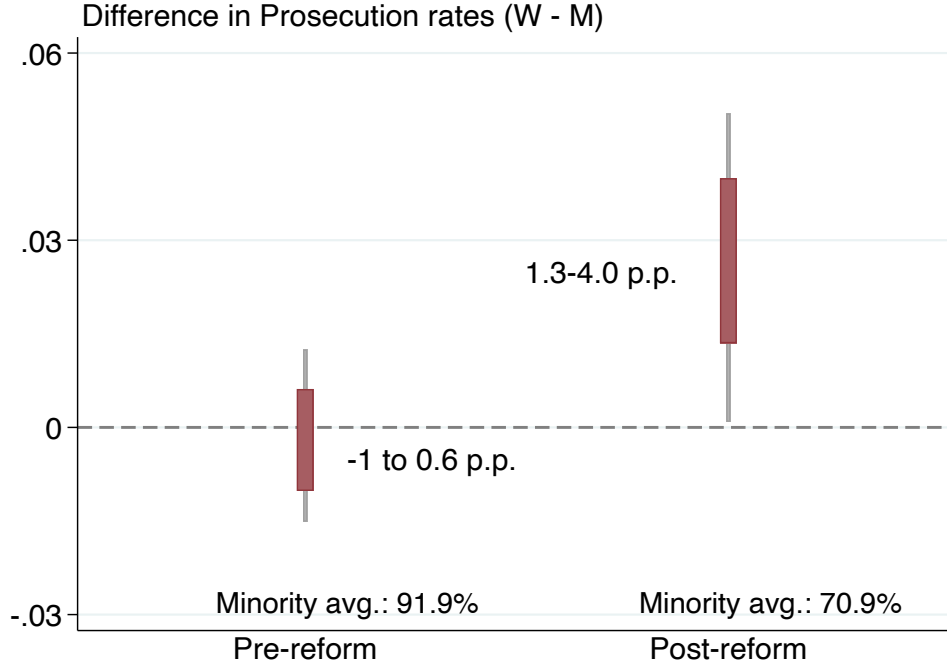
Next, we estimate bounds on the racial differences in prosecution rates that condition on having identical outcomes if prosecuted. Following Equation 3, we need, for each race, 1) the average re-offence outcomes among prosecuted defendants in each period, 2) the prosecution rate in each period and 3) the average re-offence outcomes if everyone were prosecuted. 1) and 2) are directly observed in the data, and we use bounds for 3) from Figure 11.

Figure 12 displays bounds on the average white–minority gap in prosecution rates that is conditional on having identical outcomes if prosecuted. After accounting for racial differences in the outcomes if prosecuted, we cannot reject that White and minority defendants were prosecuted at similar rates before the budget reform. Our bounds suggest that white defendants before the reform were between 0.6 p.p. **more likely** to 1 p.p. **less likely** to be prosecuted compared to their minority counterparts. While this suggests that prosecution in this context may not have been discriminatory before the reform, this does not rule out discrimination in other stages in the criminal legal system or other aspects of society.

This pattern changes dramatically after the reform, where our results suggest that white de-

⁴⁵These patterns are not due to our decision to define a broad minority subsample. Figure B9 disaggregates the average re-offence outcomes if prosecuted for minority defendants separately by the largest race/ethnicity subcategories. While there is variation across these subcategories, the average re-offence rates for non-Black and non-Hispanic defendants are not large outliers.

Figure 12: Racial differences in prosecution, conditional on prosecuted outcome (Δ_z)



Note: This figure presents bounds on the average discrimination in prosecution rates in each time period, conditional on prosecuted outcomes, $Y_i(1)$, using the approach described in Section 3. $Y_i(1)$ is whether an individual is charged with a new offence 12M after disposition, if prosecuted. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

defendants were 1.3–4 p.p. (1.8–5.6%) more likely than minority defendants to be prosecuted, after accounting for racial differences in the outcomes if prosecuted. That is, even though the budget reform results in prosecution rates falling overall, they fall by a greater amount for minority defendants than for white defendants, even after conditioning on outcomes if prosecuted.⁴⁶

Alternative approaches to estimate discrimination here yield estimates that are outside of the bounds that we estimate. ‘Selection-on-observable’ estimates that control for age, gender, criminal history and court fixed effects would estimate white–minority prosecution gaps of 1.2 p.p. before the budget reform and 4.4.p.p. after the reform. Unconditional differences in means suggest white–minority prosecution gaps of 0.9 p.p. before the budget reform and 4.3.p.p. after the reform. This means that alternative approaches to estimating discrimination in prosecution after the reform would be biased by at least 7.5%, at most 238%, and might be incorrectly-signed.

⁴⁶These findings are robust to a different definition of the ‘minority’ group. Figure B11 and Figure B12 present the average re-offence outcomes if prosecuted and discrimination estimates that include only Black and Hispanic defendants in the minority group. These estimates are qualitatively and quantitatively similar to our baseline. These findings are also robust to a more expansive definition of prosecution that includes fines as punishment. Figure B13 shows racial gaps that are qualitatively similar and contained within the baseline bounds. The racial gaps in prosecution that we estimate remain stable even if we reduce or expand the horizon we use to compute re-offence outcomes (pending disclosure review.)

5.3 Understanding drivers of racial gaps in prosecution after the reform

Our results so far document that 1) there is little evidence of discrimination in prosecution before the budget reform, and that 2) even though overall prosecution rates fall after the reform, white defendants are more likely to be prosecuted than minority defendants who would experience identical outcomes if prosecuted. Next, we investigate potential factors that could be driving this result.⁴⁷

Since the budget reform posed significant strain on resources, the relatively higher prosecution rate for white defendants (even conditional on prosecuted outcome) could be due to cases involving minority defendants requiring more resources to prosecute. Cases involving minority defendants are more likely to be backed up by weaker evidence, perhaps due to discrimination in previous stages of the criminal legal system, such as policing (Goncalves and Mello, 2021; Owens and Ba, 2021; Jordan, 2024). Since cases with weak evidence require greater prosecutor resources to obtain convictions, these cases are least likely to be pursued after the budget reform when resources became quite scarce, as prosecutors were likely to have shifted their resources to cases that they were more likely to win.

We investigate this explanation by repeating our approach to estimate discrimination in two subsamples that may vary in terms of average case quality. We classify offence categories into two bins based on the share of charges that end up successfully being punished in King County, using (pre-reform) data from September 2004 to September 2010. The logic is that for offences where the average case is typically high quality, we should see a high conversion rate of charges into punishments. Offences for which a relatively high share of charges end up being punished are: drug, DUI, property, prostitution and weapons violations. On the other hand, arrests for traffic, ‘other’ and violent offences have a relatively low share of charges that are punished, and we assume these types of cases may be lower quality.⁴⁸

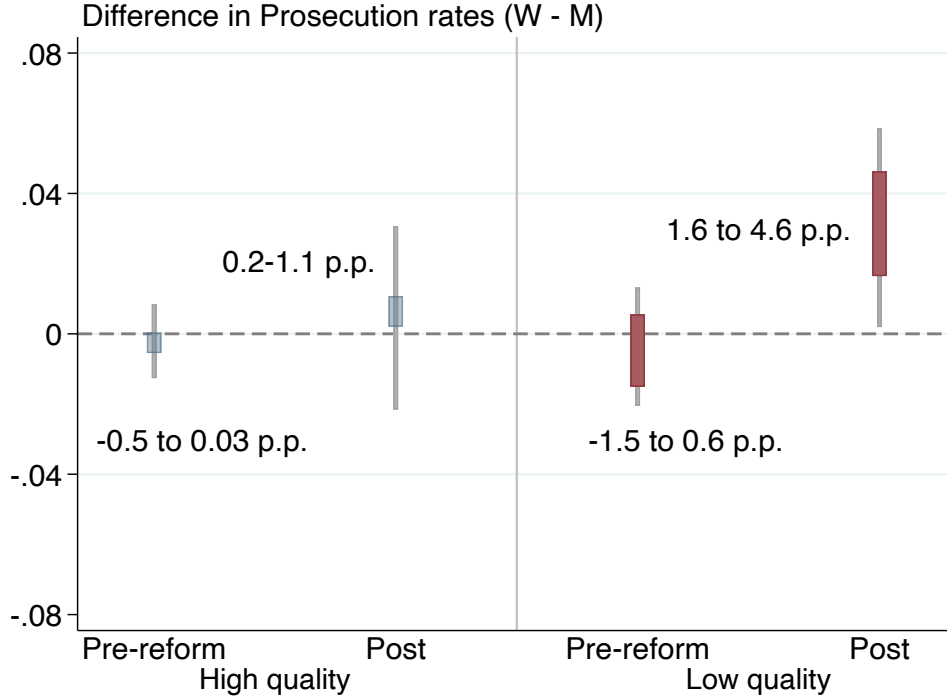
Figure 13 displays our discrimination estimates separately for the cases that may be higher in quality and cases that may be lower in quality. We see that our findings of discrimination after the reform are driven by the low quality cases. In this subsample, white defendants after the reform were 1.6–4.6 p.p. more likely than minority defendants to be prosecuted, after accounting for racial differences in the outcomes if prosecuted. In contrast, we see a gap of only 0.2 to 1.1 p.p. among the low quality subset of cases, which is much smaller and lies outside of the post-period high quality bounds. However, we cannot reject that these bounds overlap due to the reduction in power from splitting our data into two subsamples and estimating discrimination within them.⁴⁹

⁴⁷Appendix B.3 examines how prosecution rates vary by functions of potential outcomes. We see suggestive evidence that the post-reform racial gaps are more pronounced among the set of individuals who would not re-offend if prosecuted. We also find that prosecution is less likely for defendants who would commit a new offence if prosecuted. Under additional assumptions restricting the evolution of dismissed outcomes over time and restricting the support of treatment effects of prosecution, we also find suggestive evidence that prosecution is less likely in cases where it would be harmful, by generating new crime.

⁴⁸Admittedly, other factors may vary between these two categories, e.g., resource intensity.

⁴⁹An alternative exercise that comes to mind is to define the prosecuted outcome as whether the case was successfully sentenced to any punishment, and condition on that. However, such gaps would be biased by the exclusion of potential re-offence outcomes. On the other hand, the exercises above on re-offence outcomes as well as an admittedly imperfect measure of case quality. Nevertheless, Figure B10 conditions on the potential punishment outcome if a case was

Figure 13: Racial differences in prosecution, by proxy for case quality



Note: This figure presents bounds on the average discrimination in prosecution rates in each time period, conditional on prosecuted outcomes, $Y_i(1)$, using the approach described in Section 3. $Y_i(1)$ is whether an individual is charged with a new offence 12M after disposition, if prosecuted. 'High quality'/'Low quality' offences are those with a above/below median share of charges that result in any punishment using pre-reform data. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

While it is not definitive evidence, the divergence in the discrimination patterns between the high and low quality subsamples is suggestive evidence that minority defendants' cases are lower quality, and that such cases are dropped due to the budget reform. Taken seriously, this suggests that prosecutors were prosecuting most cases before the reform, and passing through any pre-existing disparities from prior stages in the criminal legal system. However, in shifting their focus to high quality cases after the budget cuts, they may have been undoing disparities from prior stages in the criminal legal system. This behaviour contrasts with the behaviour of other agents when fiscally-constrained. For example, police alter their search behaviour in a way that increase disparities when budget deficits bind (Makowsky, Stratmann, and Tabarrok, 2019). However, the patterns that we find are consistent with prior work showing that prosecutors sometimes use their discretion to attenuate discrimination from pre-prosecution decisions (Harrington and Shaffer, 2023).

prosecuted. Racial gaps from this exercise are similar to the baseline analysis in Figure 12, and we cannot reject that the bounds between the two cases do not overlap.

5.4 Conditioning on outcomes if dismissed

So far, we have defined discrimination as racial differences in prosecution, conditional on having the same outcome if prosecuted. We consider an alternate definition of discrimination that conditions on having the same outcome if **dismissed**. This definition can be interpreted as an estimate of discrimination that holds fixed some notion of the baseline “risk” that an arrested individual might re-offend. As discussed in Section 3 (Equation 7), this requires bounding outcomes if dismissed for always takers (who are always prosecuted). Given that always takers are around 80% of the population in this setting (see Figure 10), we should expect the bounds on average outcomes and discrimination to be wider here.

Again, given the time-varying nature of the potential outcomes, we need to purge the time trends in potential re-offence outcomes if dismissed ($Y_{it}(0)$) in King County using trends in $Y_{it}(0)$ in adjacent counties. Here, we make a similar parallel trends assumption as we previously did, but now for the re-offence outcomes if **dismissed**. We require parallel trends to hold between never takers and compliers (and not for always takers as in **A2**) because we need to account for time trends in the average dismissed outcomes for compliers and never takers, which we use to construct bounds for always takers.⁵⁰

A3. Re-offence outcomes if dismissed, $Y_{it}(0)$, trend similarly for never takers & compliers and is independent of county

Using this assumption, we isolate the shift in re-offence outcomes if dismissed that is due to the budget reform. Figure B14 presents estimates of the average re-offence rates if all individuals were dismissed, separately by race and time period (since potential outcomes if dismissed are allowed to vary with time). We see suggestions that minority defendants are more likely to commit a new offence if dismissed, but we cannot reject that the bounds do not overlap. For example, our estimates suggest that before the reform, between 4.3% and 15.6% of white defendants would commit a new offence if all were dismissed, while between 6.4% and 19.7% of minority defendants would commit a new offence if dismissed.⁵¹

We use these bounds on the race-specific average outcomes if dismissed to compute racial gaps in prosecution, conditional on having the same outcome if dismissed. Figure B15 shows that similar to our baseline results, we cannot reject that there is no discrimination in prosecution prior to the reform, and that white defendants are 0.9–8.2 p.p. (1.3–11.6%) more likely to be prosecuted after

⁵⁰Similar to the previous validation exercises, we test for differential pre-trends in the outcomes of dismissed individuals across county and covariate subgroups. Figure B20 shows no evidence of differential pre-trends in re-offence outcomes if dismissed across counties but within various demographic subgroups. Figure B21 finds limited evidence of differential pre-trends in re-offence outcomes if dismissed within counties but across subgroups. Almost all estimates are statistically indistinguishable from zero, which we interpret as evidence that **A3** is not grossly violated.

⁵¹The similarity of these bounds across race contrasts to other work that finds minority defendants have higher risk of re-offending (Arnold, Dobbie, and Hull, 2022). One potential reason for our findings is discrimination in policing, which could push the race-specific re-offence distributions closer together if the marginal minority defendant arrested has a lower “risk” of re-offending. However, the bounds are too wide to prove this claim.

the reform.⁵²

We redo the exercise estimating racial gaps in prosecution separately for potentially high and low quality cases, this time conditioning on re-offence outcomes if dismissed. We see patterns that are qualitatively similar to what we observe when conditioning on re-offence outcomes if prosecuted, but less precise. In Figure B16, we see that the white–minority gap after the reform lies in [1.4 p.p., 8.5 p.p.] for low quality cases and lies in [−1.4 p.p., 6.8 p.p.] for high quality cases. While this is less clear-cut than in Figure 13, the bounds on post-period gaps for the low quality cases do not contain zero, while the analogous bounds among high quality cases in the post-period do contain zero and are quite imprecise.

5.5 Summary

The results of our analysis represent the first evidence of racial discrimination in misdemeanor prosecution that directly accounts for meaningful unobservable differences across groups. We find that after a budget reform that reduces overall prosecution rates, white defendants are more likely to be prosecuted than minority defendants with similar potential re-offence outcomes. Digging deeper, our evidence suggests that prosecutors seem to be dismissing low quality resource-intensive cases, attenuating discrimination in prior stages of the criminal legal system. Finally, our findings that not being prosecuted due to the budget reform reduces future criminal activity adds to the literature on the impacts of non-prosecution.

6 Conclusion

In this paper, we show how to use a natural experiment to estimate discrimination conditional on potential outcomes (or treatment effects). We combine common forms of quasi-experimental variation that shift the likelihood of receiving some treatment with assumptions on the relationship between selection into treatment and average potential outcomes, using insights from the instrumental variables (IV) and marginal treatment effects literatures. Depending on the strength of the assumptions, we obtain bounds or point estimates. In implementing our approach with a difference-in-difference (DiD) strategy, we extend the DiD-IV literature by showing how to use selection into being an always taker, never taker or complier to estimate average potential outcomes among units that *experienced an intervention* using information on units who *did not experience the intervention*. We also present the relative advantages and disadvantages of a regression discontinuity (RD) approach to estimate discrimination. Our approach provides estimates of discrimination when groups are unobservably different and decision-makers are not randomly assigned, but a natural experiment is available. Thus, we greatly expand the set of places where researchers can study discrimination while accounting for unobserved differences in potential outcomes.

We study racial discrimination in misdemeanor prosecution, using a budget cut in King County,

⁵²These findings are robust to reducing or expanding the horizon used to compute re-offence outcomes (pending disclosure review.)

Washington that sharply reduced prosecution rates. Using a DiD strategy, we find meaningful racial differences in the unobserved re-offence outcomes. Adjusting for these differences, we find no evidence of discrimination in prosecution before the budget reform. After the reform, white defendants were more likely to be prosecuted than minority defendants with identical potential re-offence outcomes. These patterns are driven by potentially weak cases, and evidence suggests that prosecutors may be undoing discrimination from prior stages of the criminal legal system in the process. This behaviour is consistent with recent work documenting how prosecutors can attenuate pre-existing racial disparities (Harrington and Shaffer, 2023). Supplementary exercises suggest that prosecutors were less willing to prosecute cases where it would generate additional crime, although this does not vary by race.

We also study discrimination by socio-economic status (SES) in the decision to promote Michigan Public School 3rd graders to 4th grade, using a test score regression discontinuity design (Berne et al., 2023). We find meaningful SES differences in the underlying probability of succeeding in 4th grade among students at the low end of the test score distribution. Even after accounting for these underlying differences, high SES students were more likely to be promoted than low SES students, suggesting that the disparities documented by other work in this context are not solely driven by differences in unobserved potential outcomes (Westall et al., 2022a,b).

In terms of methodology, our analysis has considered conditioning only on a single potential outcome at a time. Insights from the work estimating average outcomes while accounting for multiple dimensions of unobservable heterogeneity would help quantify discrimination between individuals who are similar on multiple dimensions (Dutz et al., 2021). For example, it could permit measuring discrimination in prosecution between individuals with identical potential re-offence and employment outcomes. Additionally, extending these methods to more complex DiD settings would be useful, e.g., settings where many counties adopt a policy in a staggered fashion or where all counties eventually adopt a policy.

In terms of the empirical analysis of discrimination, future work assessing the mechanisms underlying how changing discretion (in the case of student grade promotion) and resource constraints (in the case of prosecution) would be fruitful. In the context of prosecutorial discrimination in particular, using data that can track individual events within each court case would allow us to better understand which prosecutorial actions amplify versus offset disparities.

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Appendix A Additional results & details: Student promotion

A.1 ‘Read by Grade 3’ policy details

We focus on the aspect of the ‘Read by Grade 3’ policy that required students who scored below 1252 (approximately the 5th percentile) on the Michigan standard reading test, the English Language Arts Michigan Student Test of Educational Progress (ELA M-STEP), to be retained. The exact mapping of test scores to the policy guidance is below:

- Score ≤ 1252 : The policy mandated that these students were to be retained unless they had a ‘good cause exemption’, which is described further below. These students are also supposed to receive additional supports to improve their reading skills. The supports included extra instructional time and improved instructional quality over the next school year.
- Score in $[1253, 1271]$: The policy did not mandate that these students were to be retained. These students were eligible for the additional supports that students who scored below 1252 were mandated to receive. However, this provision was not mandatory
- Score ≥ 1272 : These students are to be promoted, and there is no direct mandate or encouragement for them to receive additional academic supports.

While students who scored ≤ 1252 on the ELA M-STEP were supposed to be retained, students who met certain criteria were exempt from this requirement. This included the following students: English language learners with ≤ 3 years of English instruction, students with disabilities (i.e., with a Section 504 Plan or an Individualized Education Plan), students who have been retained before and have received supports for ≥ 2 years, students who have been enrolled in the district for ≤ 2 years and were not previously designated as having reading issues, students who later demonstrate proficiency through alternate assessments and students whose parents submit an exemption request (subject to superintendent approval) (Westall et al., 2022b).

Given that the RBG3 policy mandate includes the provision of additional academic interventions, and that this may change around the 1252 cut-off, there is concern that moving from one side of the cut-off to another may shift students across multiple treatments, biasing our estimates of average outcomes if promoted. We investigate potential bias by decomposing the reduced form treatment effect of promotion identified by this design into margin-specific treatment effects using the logic of Humphries et al. (2023).

Define the following treatment states: retention & supports (rs), promotion & no supports (pn) and promotion & supports (ps).⁵³ Let $D_i = j$ if individual i received treatment j . For simplicity, consider the RBG3 test score cut-off rule as a binary instrument, where $Z = \mathbb{I}(\text{Score} > 1252)$. We then have that $Pr(\text{Promoted} | Z = z) = Pr(D_i = pn \text{ or } D_i = ps | Z = z)$ is increasing in Z .

⁵³We rule out retention & no supports since a survey of school principals conducted by Michigan State University researchers, described in more detail below, suggest that almost all of the retained students receive some additional intervention (Berne et al., 2023).

Adopting the conditional pairwise monotonicity (CPM) assumption from Humphries et al. (2023), we permit the following set of treatment flows that occur when moving from $Z = 0$ to $Z = 1$:

- Retention & supports to promotion & no supports: $rs \rightarrow pn$
- Retention & supports to promotion & supports: $rs \rightarrow ps$
- Promotion & supports to promotion & no supports (or the reverse): $ps \rightarrow pn$ (or $pn \rightarrow ps$)

This assumption ensures that flows between treatments are weakly one way and forces individuals to only flow out of retention, not into it.

Let $\omega_{p \rightarrow q}$ denote the proportion of individuals flowing in direction $p \rightarrow q$ and let $\Delta_{p \rightarrow q}^{j-k}$ denote the treatment effect between treatments j and k for people shifted along the p and q margin. Finally, let the third flow be $ps \rightarrow pn$ for simplicity.

We then rewrite the reduced form estimate from a regression of the form $Y_i = \alpha + \beta Z_i + \varepsilon_i$ as the following expression:

$$\beta = E[Y(Z=1) - Y(Z=0)] = \omega_{rs \rightarrow pn} \Delta_{rs \rightarrow pn}^{pn-rs} + \omega_{rs \rightarrow ps} \Delta_{rs \rightarrow ps}^{ps-rs} + \underbrace{\omega_{ps \rightarrow pn} \Delta_{ps \rightarrow pn}^{pn-ps}}_{\text{Bias}}$$

The above expression shows that the reduced form estimates of the effect of the RBG3 test score cut-off on outcomes is a weighted average of the treatment effect of 1) promotion without supports relative to retention (Δ^{pn-rs}), 2) promotion & supports relative to retention (Δ^{ps-rs}) and 3) additional supports with promotion relative to promotion without supports. A weighted average of the first two treatment effects can be interpreted as a total effect of promotion relative to retention and does not necessarily represent bias. However, term 3) contaminates the reduced form estimates with the effect of supports.⁵⁴

This bias term will be irrelevant if $\omega_{ps \rightarrow pn} = 0$. While it is not possible to test this directly, we rely on analysis of a survey of around **[pending disclosure]** principals conducted by researchers at Michigan State University (Berne et al., 2023). Each principal was asked for a list of the additional supports they provided students in 3 different categories during the 2021-22 school year: students who scored below 1252 and were retained, students who scored below 1252 and were promoted, and students who scored above 1252. For each of the 11 possible interventions listed in the survey, they compare the difference between the share of principals who report offering the intervention to a) students who scored below 1252 and were promoted and to b) students who scored above 1252 and were promoted. The change in the probability of receiving any intervention around the cut-off is small **[pending disclosure]** and is marginally significant ($p = \text{[pending disclosure]}$). Additionally, a recent study one of the key interventions using the RBG3 RD design finds no

⁵⁴This bias term arises under the CPM assumption, but not under more restrictive monotonicity assumptions. For example, if we were to assume unordered partial monotonicity instead, the only permissible flows would be $rs \rightarrow pn$ and $rs \rightarrow ps \implies \omega_{ps \rightarrow pn} = 0$, implying that the bias term is 0 (Mountjoy, 2022).

evidence of changes in the probability of being assigned a “highly effective” teacher around the test score cut-off (Westall, Strunk, and Utter, 2023). Taken together, we interpret these findings as evidence that this type of bias is minimal in this context.

A.2 Robustness checks

Figure A1: Smoothness of density of test score distribution around cut-off

[pending disclosure]

Note: These figures present results of the Cattaneo, Jansson, and Ma (2018) density test for the smoothness of the running variable. The x-axis represents the running variable, the 3rd grade ELA M-STEP, re-centred by the cut-off of 1252. The sample includes students who took the 3rd grade ELA M-STEP for the first time between 2020 and 2022 and scored within 10 points of the cut-off.

Figure A2: Smoothness of demographics around test score cut-off

[pending disclosure]

Note: Each Panel presents RD estimates investigating the impact of the RBG3 test score-based promotion policy on the listed baseline covariate, using a local linear specification. The x-axis represents the running variable, the 3rd grade ELA M-STEP, re-centred by the cut-off of 1252. The sample includes students who took the 3rd grade ELA M-STEP for the first time between 2020 and 2022 and scored within 10 points of the cut-off. ‘RD estimate’ presents β from $X_i = \alpha + \beta \mathbb{I}(\text{Score}_i > 1252) + \delta_1 \text{Score}_i + \delta_2 \mathbb{I}(\text{Score}_i > 1252) \times \text{Score}_i + \varepsilon_i$. Standard errors are clustered at the level of the running variable.

Figure A3: Smoothness of additional academic programming around test score cut-off

[pending disclosure]

Note: Each Panel presents RD estimates investigating the impact of the RBG3 test score-based promotion policy on the listed baseline covariate, using a local linear specification. The x-axis represents the running variable, the 3rd grade ELA M-STEP, re-centred by the cut-off of 1252. The sample includes students who took the 3rd grade ELA M-STEP for the first time between 2020 and 2022 and scored within 10 points of the cut-off. ‘RD estimate’ presents β from $X_i = \alpha + \beta \mathbb{I}(\text{Score}_i > 1252) + \delta_1 \text{Score}_i + \delta_2 \mathbb{I}(\text{Score}_i > 1252) \times \text{Score}_i + \varepsilon_i$. Standard errors are clustered at the level of the running variable.

Figure A4: Smoothness of predicted ELA M-STEP next year around test score cut-off

[pending disclosure]

Note: These figures present RD estimates investigating the impact of the RBG3 test score-based promotion policy on the predicted ELA M-STEP score (in standard deviation units) taken in the following school year (regardless of grade), using demographics, LEP and special education status, whether the student was previously retained, whether the student is new to the district, and school fixed effects. ‘RD estimate’ presents β from $X_i = \alpha + \beta \mathbb{I}(\text{Score}_i > 1252) + \delta_1 \text{Score}_i + \delta_2 \mathbb{I}(\text{Score}_i > 1252) \times \text{Score}_i + \varepsilon_i$. Standard errors are clustered at the level of the running variable. The x-axis represents the running variable, the 3rd grade ELA M-STEP, re-centred by the cut-off of 1252. The sample includes students who took the 3rd grade ELA M-STEP for the first time between 2020 and 2022 and scored within 10 points of the cut-off.

Table A1: 4th grade M-STEP proficiency levels

		Level 1	Level 2	Level 3	Level 4
	Grade	Not proficient	Partially proficient	Proficient	Advanced
ELA	3	1203-1279	1280-1299	1300-1316	1317-1357
Math	3	1217-1280	1281-1299	1300-1320	1321-1361
ELA	4	1301-1382	1383-1399	1400-1416	1417-1454
Math	4	1310-1375	1376-1399	1400-1419	1420-1455

Note: From page 15 of Spring 2023 Interpretive Guide to M-STEP reports (Michigan Department of Education, 2023).

Figure A5: Distribution of placebo estimates of discontinuity in treated outcomes

[pending disclosure]

Note: These figures present the distribution of estimates of the discontinuity in treated outcomes obtained by using alternate values of the running variable as the cut-off. We use each value in the $[-5, 90]$ interval as the cut-off, where 0 is the true cut-off, but keep the bandwidth fixed at 10 points on either side of the cut-off, as in the baseline. The vertical lines display the observed RD estimate that we obtain in Figure 3. ‘Pr(Greater magnitude estimate)’ computes the share of placebo estimates that are greater in magnitude than the observed RD estimate. The treated outcome is whether a student demonstrated any proficiency on both the Math and ELA M-STEP in 4th grade, as defined in Table A1. The sample and specification details are the same as described in Figure 3.

Figure A6: Average outcomes if promoted by compliance group ($Y_i(1)$)

[pending disclosure]

Note: This figure shows the average treated outcomes for always takers (‘AT’), compliers (‘CT’) and never takers (‘NT’). The treatment is promotion and the treated outcome is whether a student demonstrated any proficiency on both the Math and ELA M-STEP in 4th grade, as defined in Table A1. The bounds for the treated outcomes for never takers and compliers come from the assumption of weak monotonicity of the relationship between treated outcomes and treatment propensities, and that $Y_i(1) \in \{0, 1\}$.

Table A2: Testing effect of test score on promotion and promoted outcomes

[pending disclosure]

Note: This presents estimates of $X_i = \alpha + \beta \mathbb{I}(\text{Score}_i > 1252) + \delta_1 \text{Score}_i + \delta_2 \mathbb{I}(\text{Score}_i > 1252) \times \text{Score}_i + \varepsilon_i$, where X_i is either an indicator for promotion or the proficiency outcome if promoted. The ‘Proficient’ columns only include promoted students. Standard errors are clustered at the level of the running variable.

Figure A7: Average outcomes if promoted, excluding students whose parents requested exemptions

[pending disclosure]

Note: This figure presents bounds on the average treated outcome obtained using the approach described in Section 3. The treatment is promotion and the treated outcome is whether a student demonstrated any proficiency on both the Math and ELA M-STEP in 4th grade, as defined in Table A1. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap. The p -value is from a formal bootstrapped test of whether the identified sets overlap, described in Appendix C.5.

Figure A8: SES differences in promotion, excluding students whose parents requested exemptions

[pending disclosure]

Note: This figure presents bounds on the average discrimination in promotion rates, conditional on treated potential outcomes, using the approach described in Section 3. The treatment is promotion and the treated outcome, denoted by $Y_i(1)$, is whether a student demonstrated any proficiency on both the Math and ELA M-STEP in 4th grade, as defined in Table A1. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Figure A9: Promotion rates at the cut-off, conditional on promoted outcome (π_{0ry})

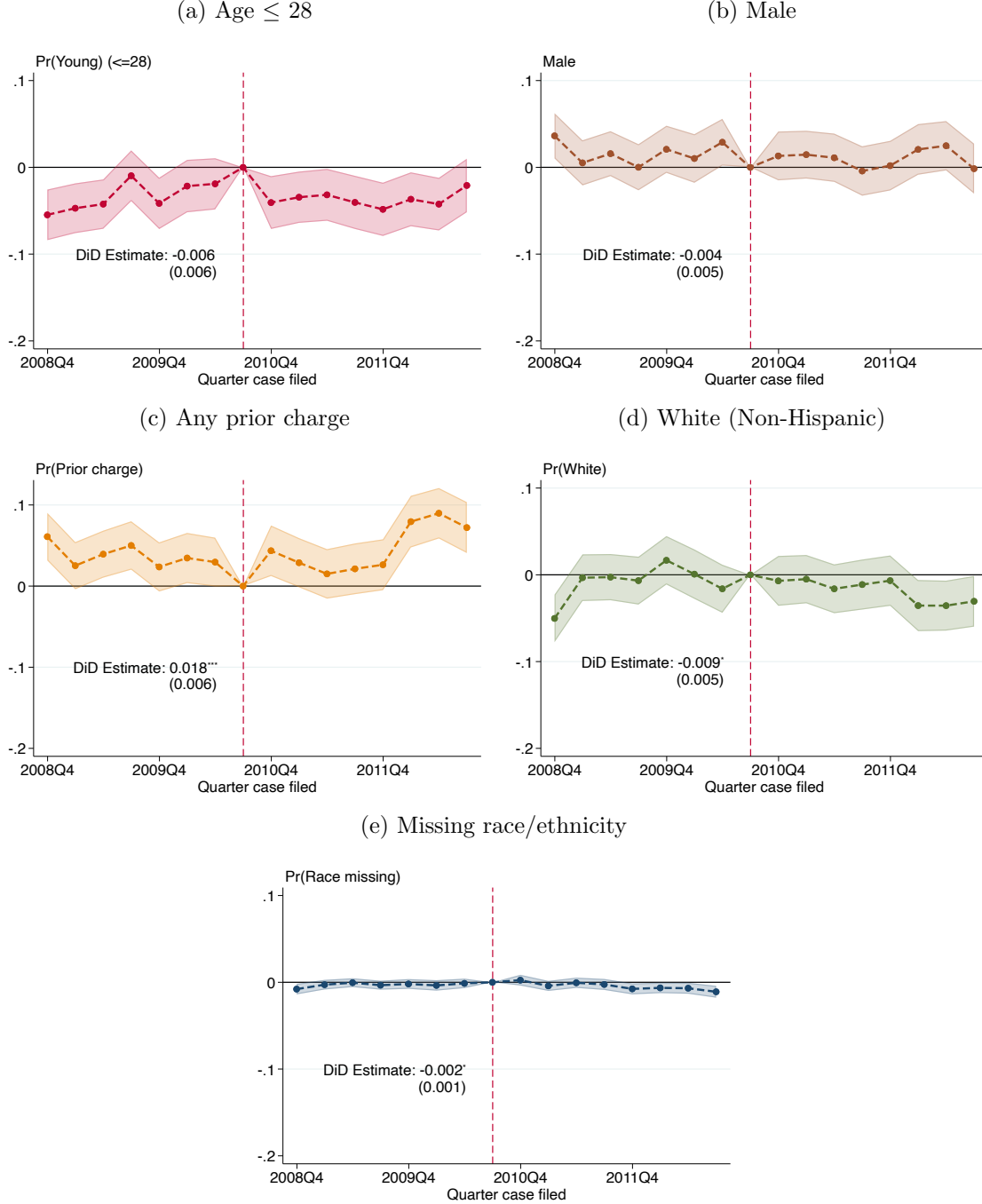
[pending disclosure]

Note: This figure presents bounds on the average prosecution rates for each SES group, conditional on promoted outcomes, $Y_i(1)$, using the approach described in Section 3. $Y_i(1)$ is whether a student demonstrated any proficiency on both the Math and ELA M-STEP in 4th grade, as defined in Table A1. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Appendix B Additional results: Misdemeanor prosecution

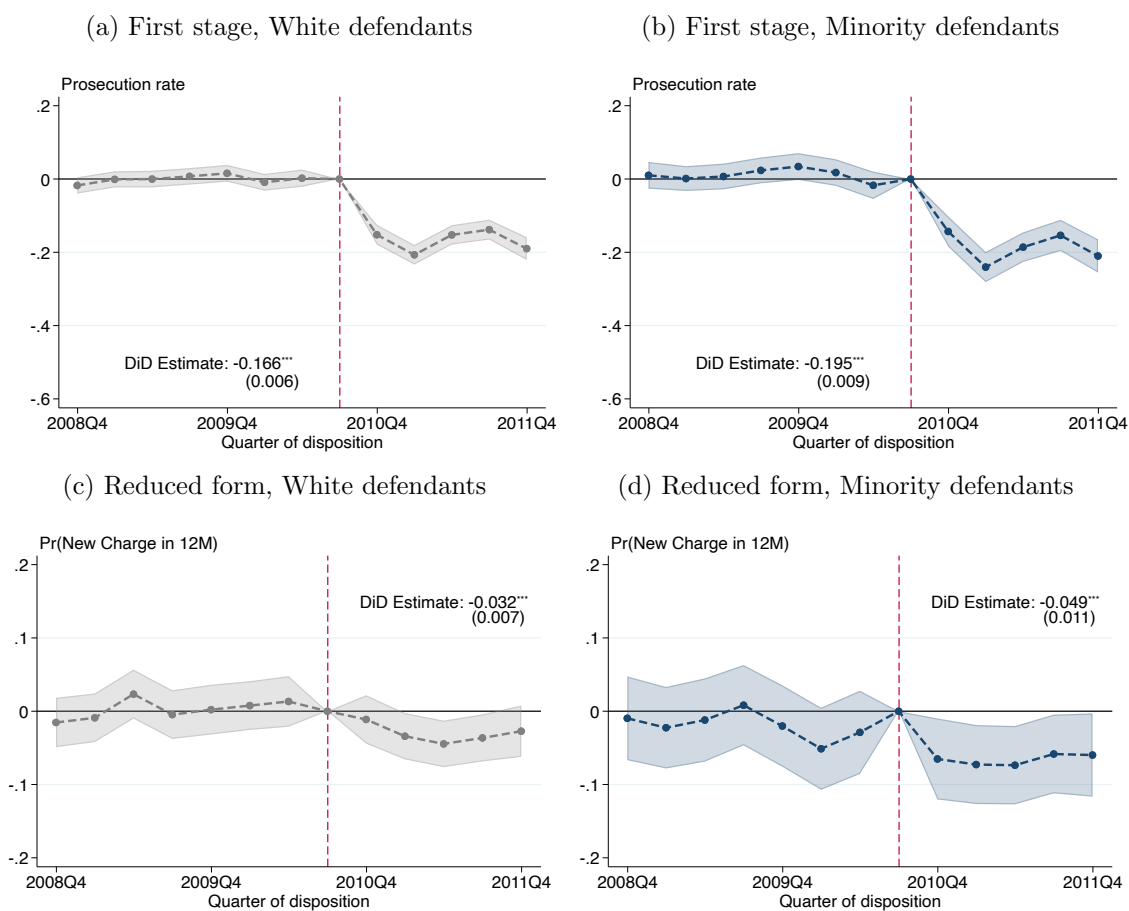
B.1 Robustness checks

Figure B1: Impact of budget reform on caseload characteristics



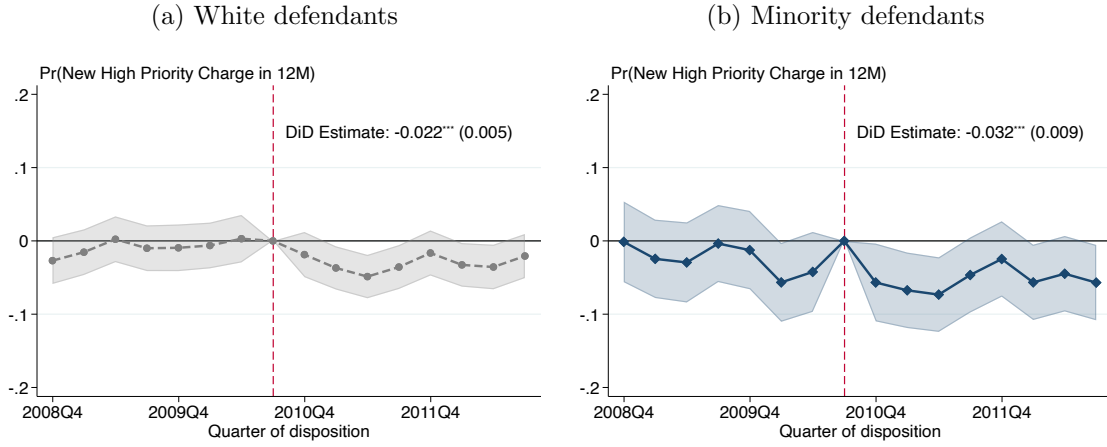
Note: Each Panel presents event study estimates investigating the impact of the King County budget reform. ‘DiD estimate’ is β^{DD} from $Y_{igt} = \alpha + \delta_1 \mathbb{I}[\text{King County}] + \delta_2 \text{Post}_i + \beta^{DD} \mathbb{I}[\text{King County}] \times \text{Post}_i + \epsilon_{igt}$, where $\text{Post}_i = 1$ if the case is filed on or after September 28, 2010, when the budget reform was announced. ‘Young’ denotes defendants who were at most 28 years old at disposition and ‘Any Prior’ is an indicator for whether an individual has ever been previously charged with an offence in Washington State. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

Figure B2: Robustness of first stage and reduced form to excluding post-SPD investigation period



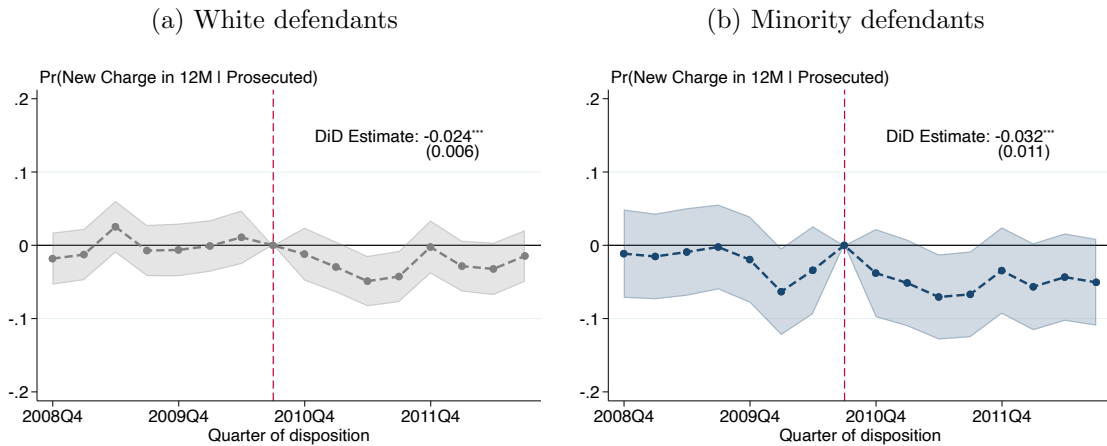
Note: This identical to Figure 6 and Figure 7 except excludes cases disposed of after December 11, 2011.

Figure B3: Impact of King County budget reform on new ‘high-priority’ offences over 12M



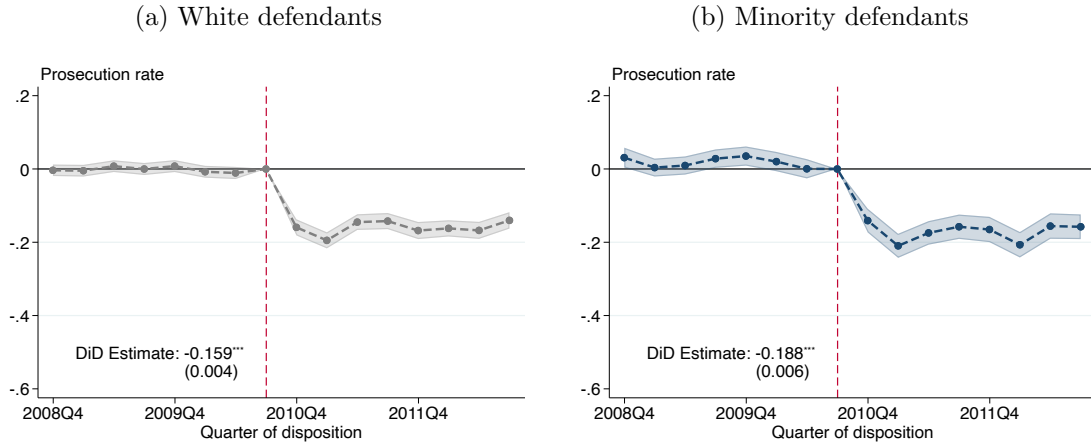
Note: Each Panel presents event study estimates investigating the impact of the King County budget reform. The re-offence outcome includes any ‘high-priority’ charges filed against an individual anywhere in Washington State. ‘High-priority’ cases are those that are not associated with charges that were commonly dismissed in the 2 quarters after the budget reform. Sample includes all misdemeanor defendants, as described in [Table 2](#). ‘DiD Estimate’ pools the coefficients on relative time indicators and estimates $Y_{igt} = \alpha + \delta_1 \mathbb{I}[\text{King County}] + \delta_2 Post_i + \beta^{DD} \mathbb{I}[\text{King County}] \times Post_i + \epsilon_{igt}$, where $Post_i = 1$ if the case is disposed of on or after September 28, 2010, when the budget reform was announced. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

Figure B4: Impact of King County budget reform on new offences over 12M, only prosecuted defendants



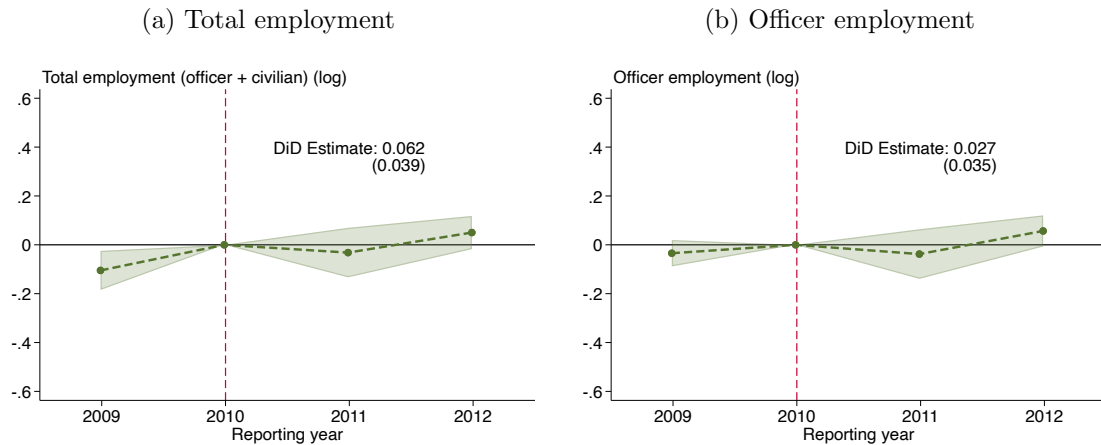
Note: Each Panel is identical to [Figure 7](#), except the sample only includes prosecuted defendants.

Figure B5: Robustness of first stage to more expansive prosecution decision



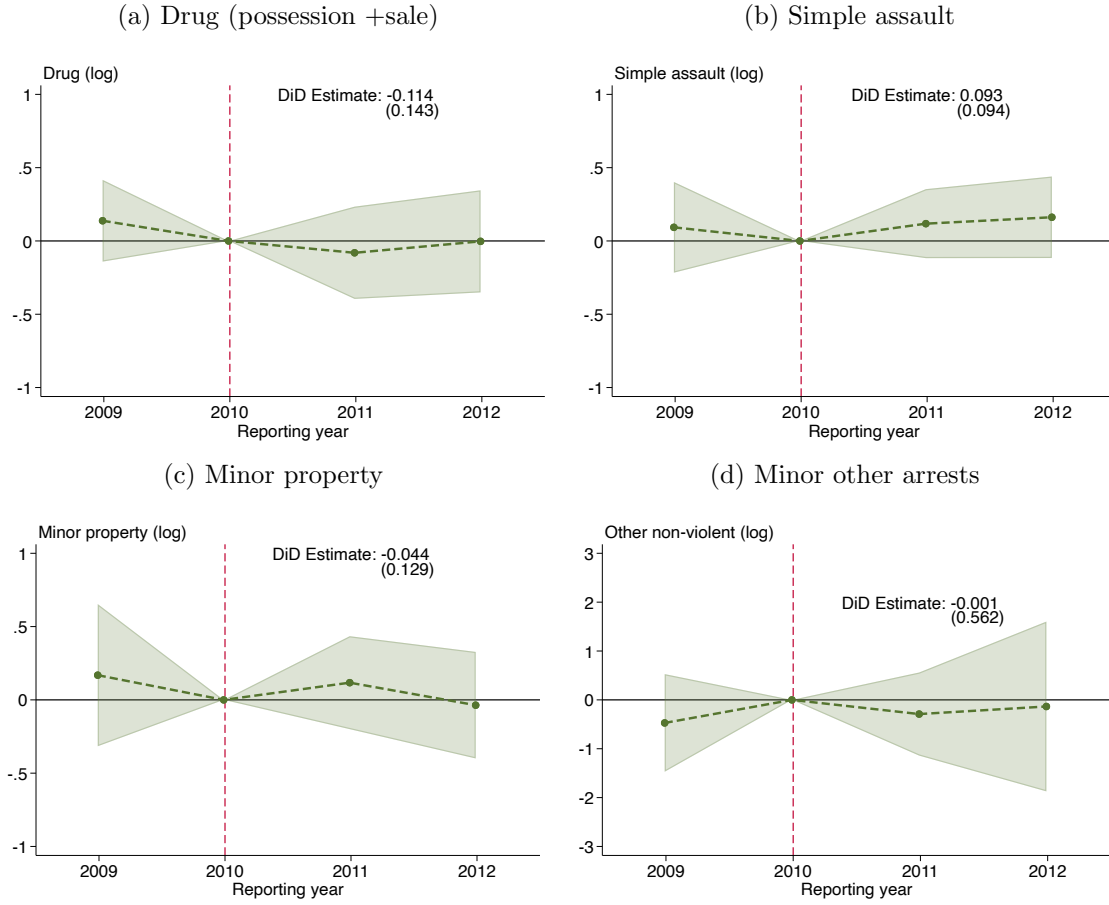
Note: This identical to [Figure 6](#) except includes cases listed as ‘Dismissed’ but with a fine as part of the sentence as prosecuted.

Figure B6: Impact of budget reform on log police employment



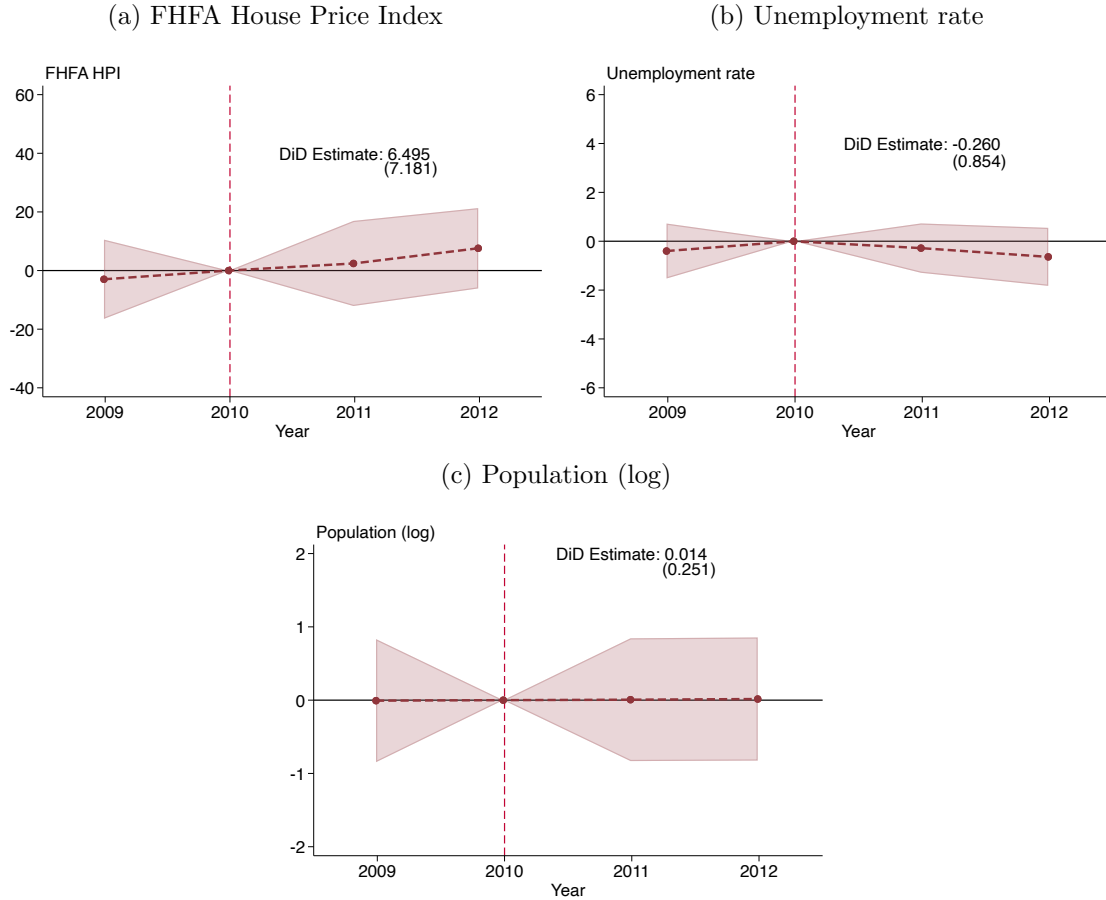
Note: Estimates generated using annual average employment from the Law Enforcement Officers Killed and Assaulted (LEOKA) data (Kaplan, 2023). This specification is similar to those used to estimate the first stage and reduced form except for the inclusion of originating agency (ORI) fixed effects and usage of the average pre-reform county-level population as weights. ORIs in areas with an annual population average less than 1,000 or with zero employment counts throughout the sample are excluded. 95% confidence intervals are constructed using standard errors clustered at the ORI level.

Figure B7: Impact of budget reform on per capita arrests



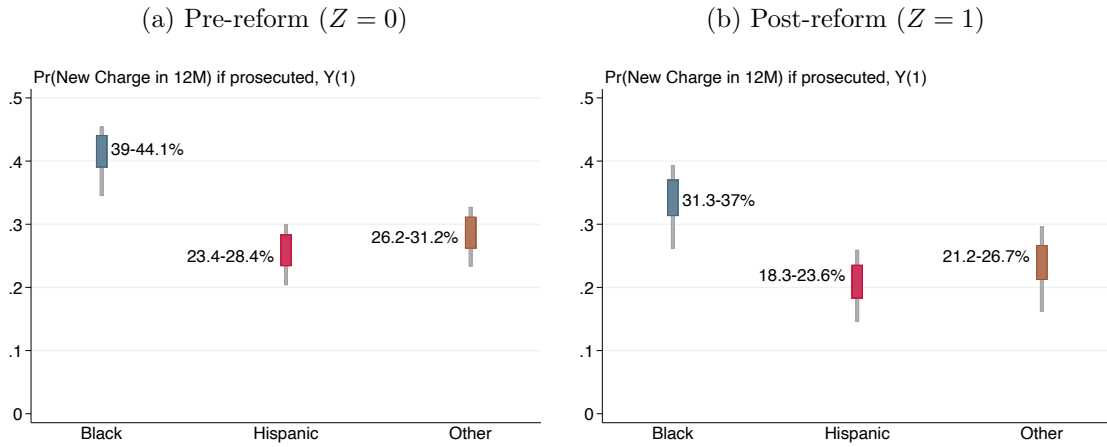
Note: Estimates generated using annual number of arrests from Uniform Crime Report (UCR) data (Kaplan, 2023). ‘Minor property’ arrests include arrests for stolen property, fraud, forgery and theft. This specification is similar to those used to estimate the first stage and reduced form except for the inclusion of originating agency (ORI) fixed effects and usage of the average pre-reform county-level population as weights. ORIs in areas with an annual population average less than 1,000, with limited time coverage between 2008-13 or with zero arrest counts in a given year are excluded. 95% confidence intervals are constructed using standard errors clustered at the ORI level.

Figure B8: Impact of budget reform on non-crime economic factors



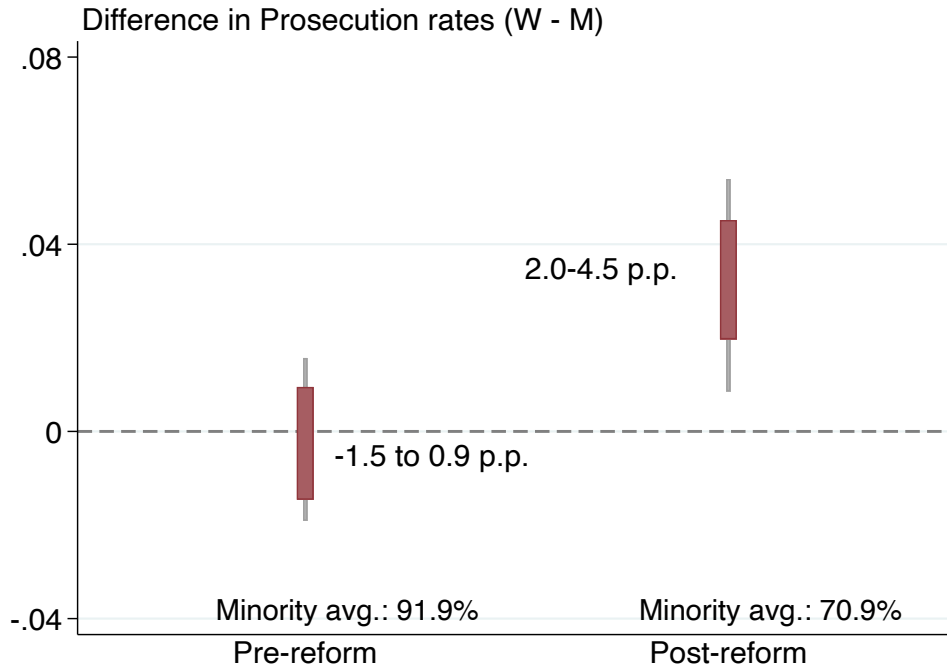
Note: The specification underlying these figures is used to estimate the first stage and reduced form except for the usage of the average pre-reform county-level population as weights (except Panel (c) is unweighted). County-level data on house prices are from the Federal Housing Finance Agency (FHFA), unemployment rates from Local Area Unemployment Statistics and population counts are from the Census Bureau. 95% confidence intervals are constructed using heteroskedasticity-robust standard errors .

Figure B9: Disaggregated average outcomes if prosecuted by minority subgroup



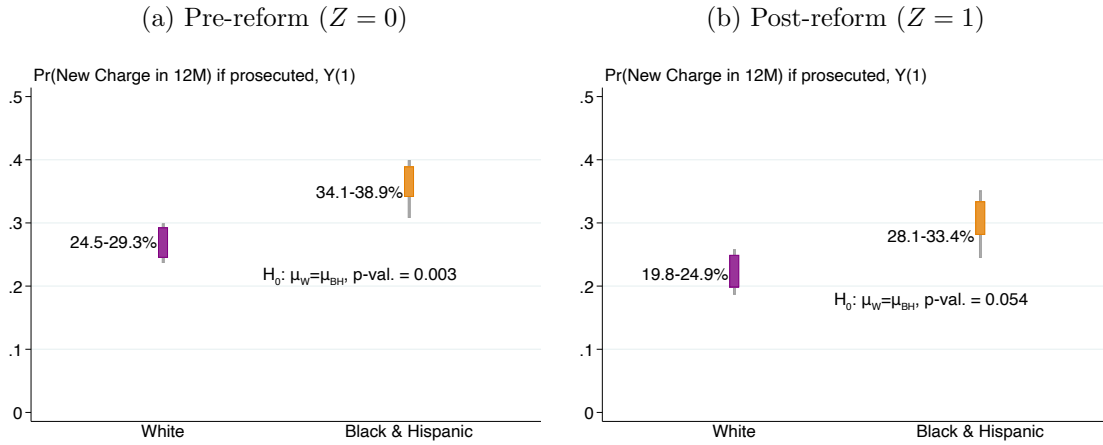
Note: This figure presents bounds on the average treated outcome obtained using the approach described in Section 3, separately by time period and subgroups within minority defendants. The treatment is prosecution and the treated outcome is whether an individual is charged with a new offence 12M after disposition, if prosecuted. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Figure B10: Racial differences in prosecution, conditional on any punishment sentenced, if prosecuted (Δ_z)



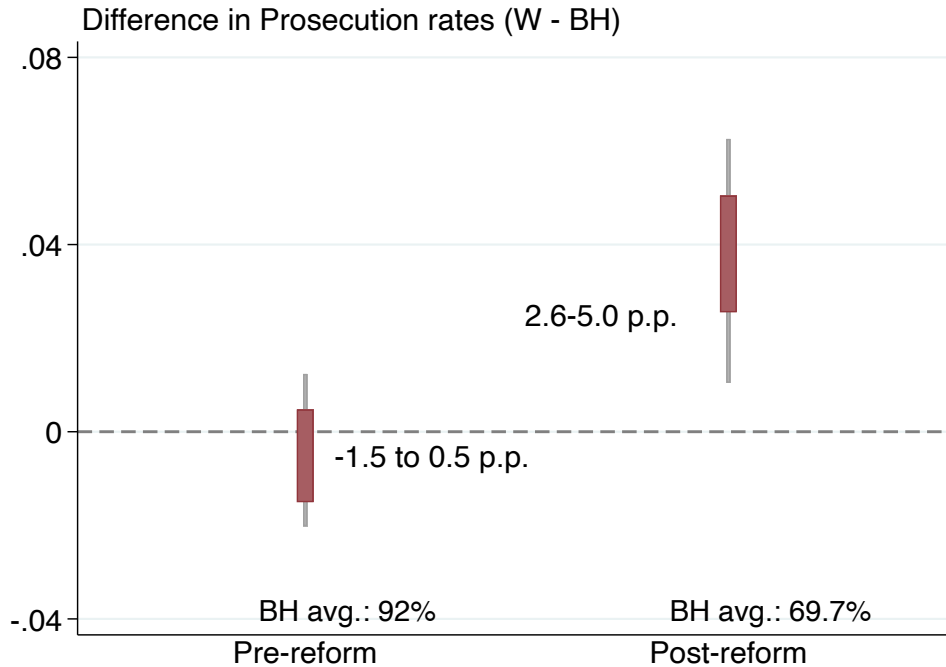
Note: This figure presents bounds on the average discrimination in prosecution rates in each time period, conditional on case outcome if prosecuted, $Y_i(1)$, using the approach described in Section 3. $Y_i(1)$ is whether an individual is sentenced to any non-fine punishment, if prosecuted. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Figure B11: Average outcomes if prosecuted, White vs. Black/Hispanic defendants



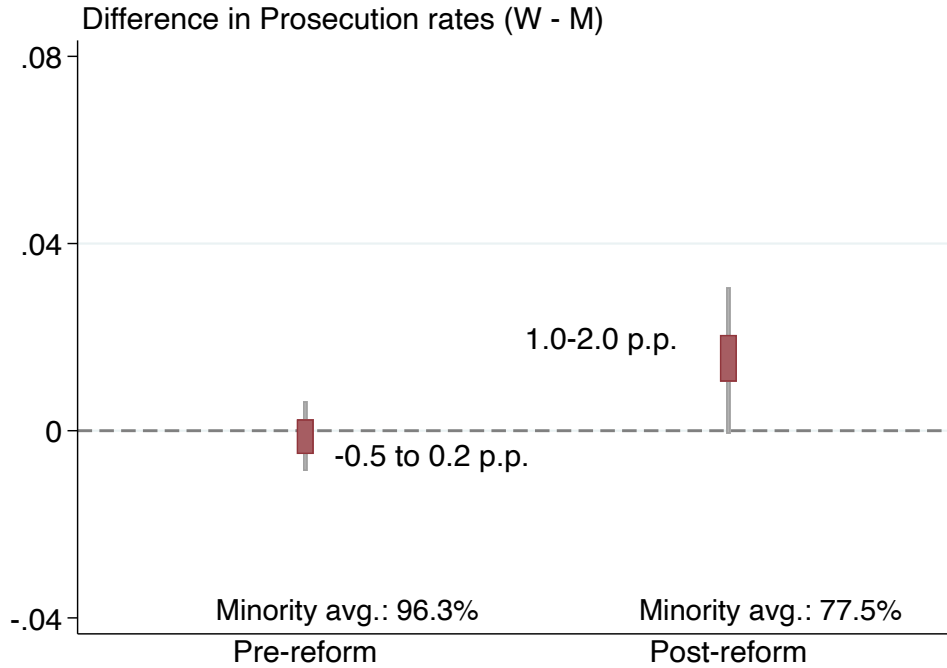
Note: This figure presents bounds on the average treated outcome obtained using the approach described in Section 3, separately by race and time period. The treatment is prosecution and the treated outcome is whether an individual is charged with a new offence 12M after disposition, if prosecuted. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap. The p-value is from a formal bootstrapped test of whether the identified sets overlap, described in Appendix C.5.

Figure B12: Racial differences in prosecution conditional on prosecuted outcome, White vs. Black/Hispanic defendants



Note: This figure presents bounds on the average discrimination in prosecution rates in each time period, conditional on prosecuted outcomes, $Y_i(1)$, using the approach described in Section 3. $Y_i(1)$ is whether an individual is charged with a new offence 12M after disposition, if prosecuted. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Figure B13: Racial differences in prosecution conditional on prosecuted outcome: More expansive prosecution decision

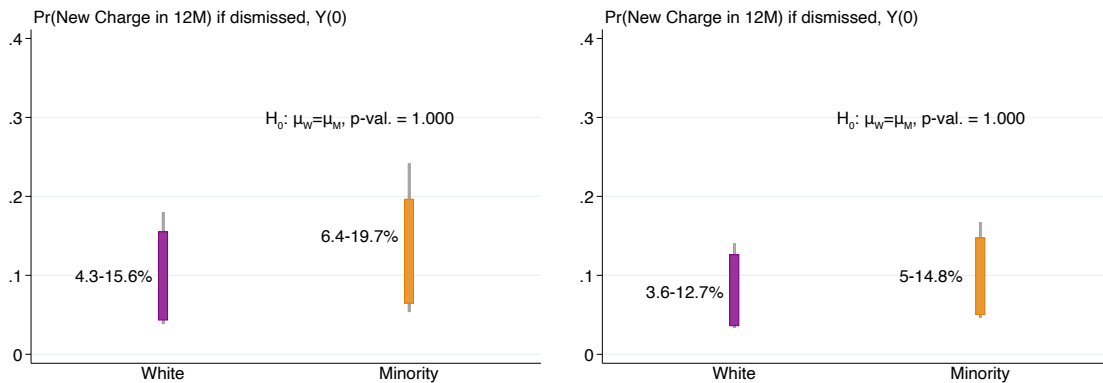


Note: This figure presents bounds on the average discrimination in prosecution rates in each time period, conditional on prosecuted outcomes, $Y_i(1)$, using the approach described in Section 3. $Y_i(1)$ is whether an individual is charged with a new offence 12M after disposition, if prosecuted. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Figure B14: Average outcomes if dismissed, $E[Y_{it}(0)|R_i = r]$

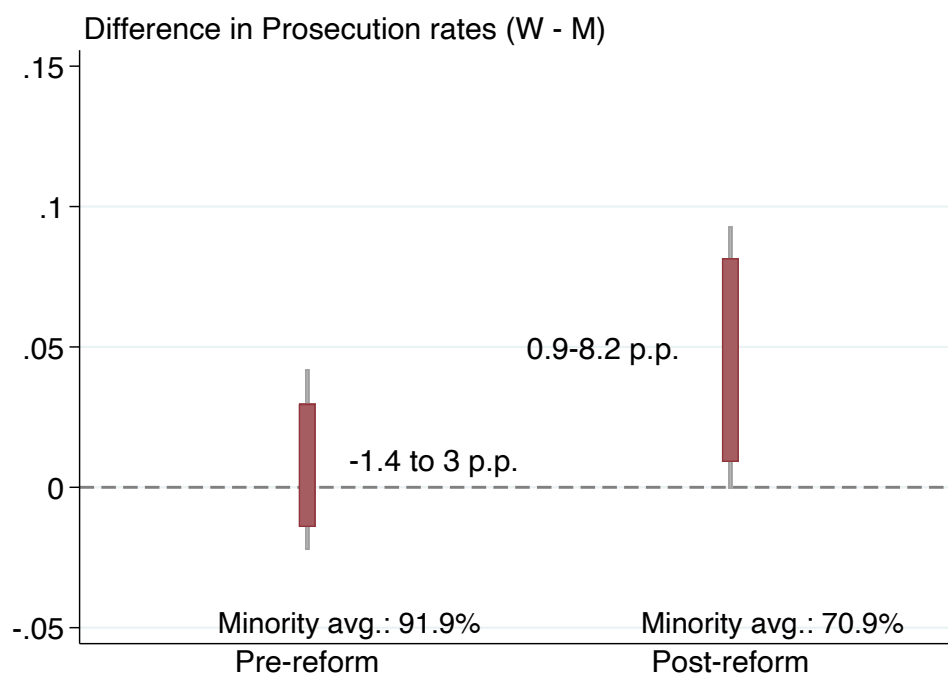
(a) Pre-reform ($Z = 0$)

(b) Post-reform ($Z = 1$)



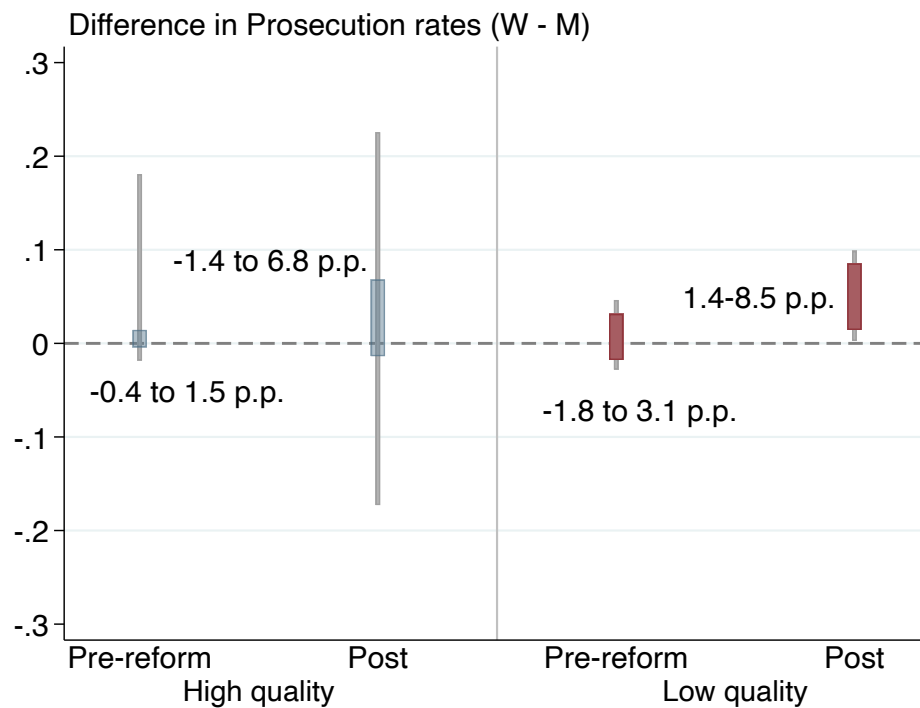
Note: This figure presents bounds on the average untreated outcome obtained using the approach described in Section 3, separately by race and time period. The treatment is prosecution and the untreated outcome is whether an individual is charged with a new offence 12M after disposition, if dismissed. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Figure B15: Racial differences in prosecution, conditional on dismissed outcome (Δ_z)



Note: This figure presents bounds on the average discrimination in prosecution rates in each time period, conditional on dismissed outcomes, $Y_i(0)$, using the approach described in Section 3. $Y_i(0)$ is whether an individual is charged with a new offence 12M after disposition, if dismissed. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

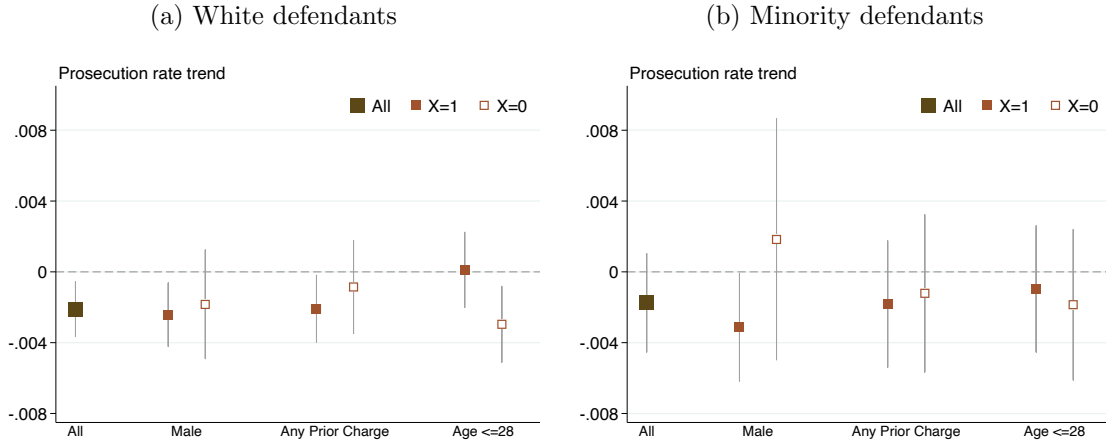
Figure B16: Racial differences in prosecution, by proxy for case quality: conditional on dismissed outcome



Note: This figure presents bounds on the average discrimination in prosecution rates in each time period, conditional on dismissed outcomes, $Y_i(0)$, using the approach described in Section 3. $Y_i(0)$ is whether an individual is charged with a new offence 12M after disposition, if dismissed. 'High quality'/'Low quality' offences are those with a above/below median share of charges that result in any punishment using pre-reform data. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

B.2 Testing DiD adjustment assumptions

Figure B17: Prosecution trends in adjacent counties, by covariate subgroup



Note: Each coefficient is from estimating a linear regression of prosecution on a linear quarterly trend using pre-period data in the counties adjacent to King County, among the subgroup, where X denotes whether the dummy is equal to 1 or not. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

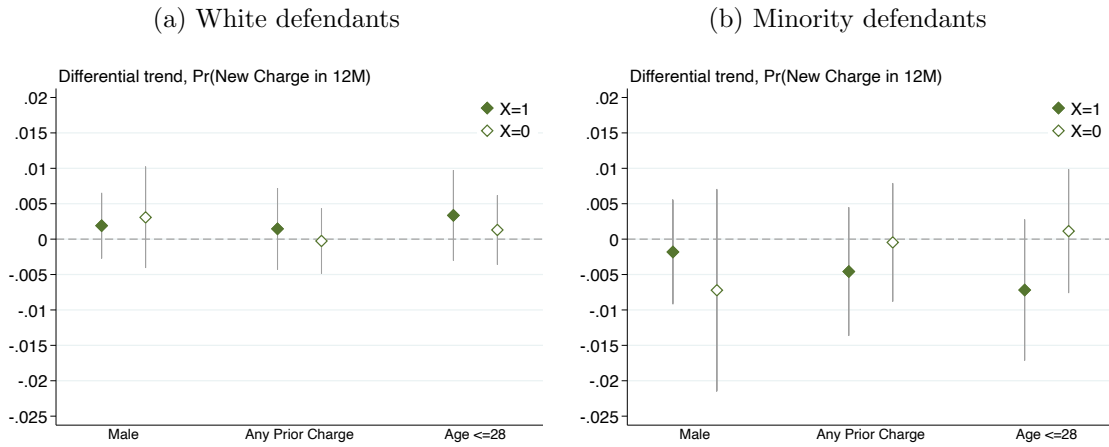
Figure B18 and Figure B20 estimate the following regression & tests the hypotheses listed below it:

$$\begin{aligned}
 Y_{itg} = & \beta_1 t + \beta_2 X_i + \beta_3 \text{King County} + \\
 & \delta_1 X_i \times t + \delta_2 X_i \times \text{King County} + \delta_3 t \times \text{King County} + \\
 & \delta_4 X_i \times t \times \text{King County} + \varepsilon_{igt} \\
 X = 0 : & H_0 : \delta_3 = 0 \\
 X = 1 : & H_0 : \delta_3 + \delta_4 = 0
 \end{aligned}$$

Figure B19 and Figure B21 estimates the following regression & tests the hypotheses listed below it:

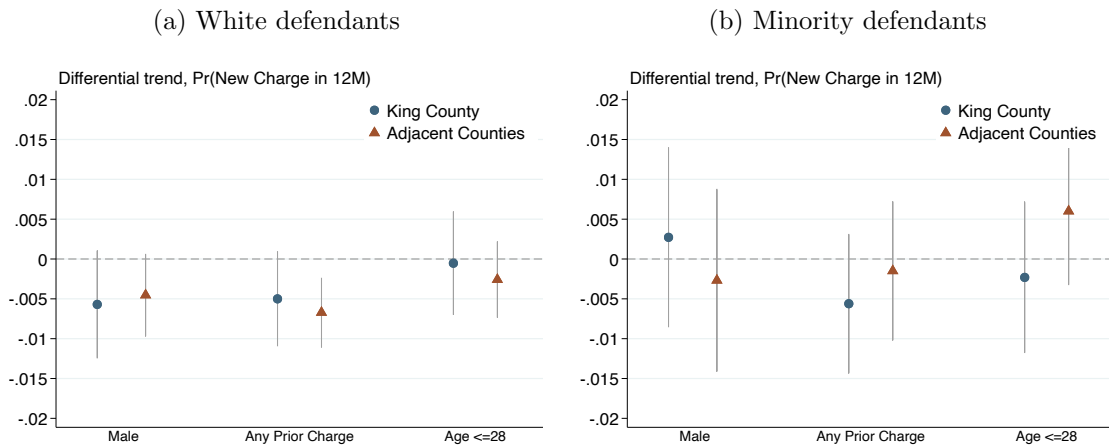
$$\begin{aligned}
 Y_{itg} = & \beta_1 t + \beta_2 X_i + \beta_3 \text{King County} + \\
 & \delta_1 X_i \times t + \delta_2 X_i \times \text{King County} + \delta_3 t \times \text{King County} + \\
 & \delta_4 X_i \times t \times \text{King County} + \varepsilon_{igt} \\
 \text{King County } & H_0 : \delta_1 + \delta_4 = 0 \\
 \text{Adjacent } & H_0 : \delta_1 = 0
 \end{aligned}$$

Figure B18: Testing equal trends in group-specific treated outcomes across counties



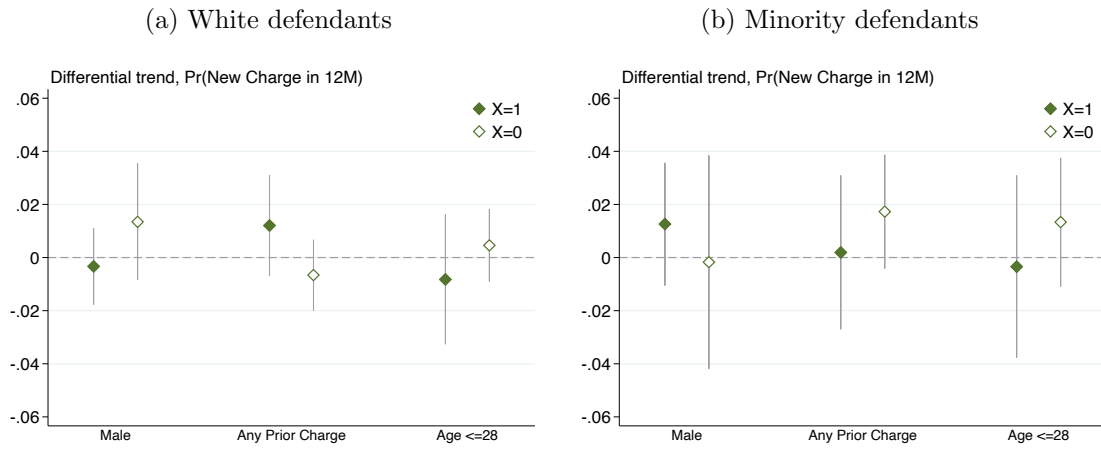
Note: Each coefficient is an estimate of the difference in pre-period trends in treated outcomes (outcomes if prosecuted) across counties, for a given covariate value. The sample only includes individuals who are prosecuted prior to the budget reform. For example, the first green diamond in Panel a) represents the difference in trends in treated outcomes for white male defendants between King County and other counties. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

Figure B19: Testing equal trends in treated outcomes between groups, within each county



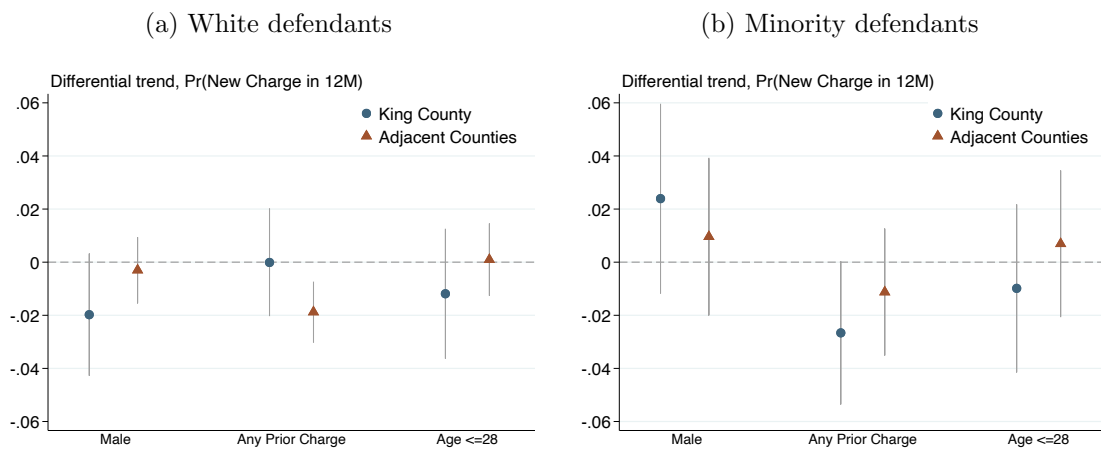
Note: Each coefficient is an estimate of the difference in pre-period trends in treated outcomes (outcomes if prosecuted) across covariate groups, within a given county. The sample only includes individuals who are prosecuted prior to the budget reform. For example, the first blue circle in Panel a) represents the difference in trends in treated outcomes between white male and female defendants in King County. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

Figure B20: Testing equal trends in group-specific untreated outcomes across counties



Note: Each coefficient is an estimate of the difference in pre-period trends in untreated outcomes (outcomes if not prosecuted) across counties, for a given covariate value. The sample only includes individuals who are dismissed prior to the budget reform. For example, the first green diamond in Panel a) represents the difference in trends in untreated outcomes for white male defendants between King County and other counties. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

Figure B21: Testing equal trends in untreated outcomes between groups, within each county

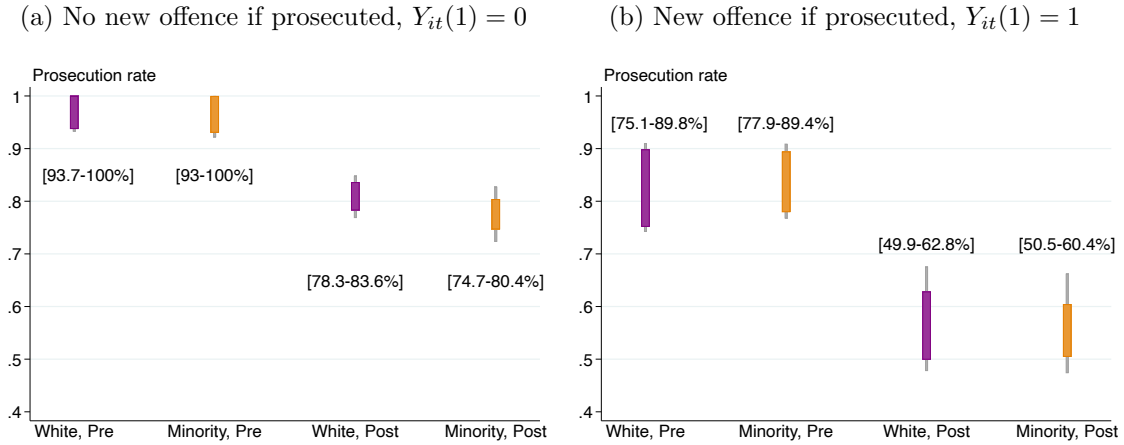


Note: Each coefficient is an estimate of the difference in pre-period trends in untreated outcomes (outcomes if not prosecuted) across covariate groups, within a given County. The sample only includes individuals who are dismissed prior to the budget reform. For example, the first blue circle in Panel a) represents the difference in trends in untreated outcomes between white male and female defendants in King County. 95% confidence intervals are constructed using heteroscedasticity-robust standard errors.

B.3 Examining how prosecution varies by potential outcomes and treatment effects

Here we discuss how the race-, time period- and potential outcome-specific prosecution rates, which are the building blocks of our discrimination estimates (see Equation 3), provide some evidence on prosecution decisions in this setting. We start by conditioning on re-offence outcomes if prosecuted, and Figure B22 presents estimates of prosecution rates separately by race, time period, and whether individuals **would not** commit a new offence if prosecuted ($Y_i(1) = 0$) or **would** commit a new offence if prosecuted ($Y_i(1) = 1$).⁵⁵

Figure B22: Prosecution rates, conditional on prosecuted outcome (π_{zry})



Note: This figure presents bounds on the average prosecution rates for each race group and time period, conditional on prosecuted outcomes, $Y_i(1)$, using the approach described in Section 3. $Y_i(1)$ is whether an individual is charged with a new offence 12M after disposition, if prosecuted. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Panel a) of Figure B22 focuses on prosecution rates for individuals who would not commit a new offence if prosecuted ($Y_i(1) = 0$). The first two estimates are prosecution rates before the reform (“Pre”) and the following two estimates are prosecution rates after the reform (“Post”). We see that among defendants who would not commit a new offence if prosecuted, prosecution rates before the reform are similar across race. However, we see suggestions that the drop after the reform is greater for minority defendants. Prosecution rates for white defendants falls from 93.7%–100% to between 78.3%–83.6%. Prosecution rates for minority defendants fall from a similar pre-reform level to 74.7%–80.4%. This is not the case in Panel b), which displays the analogous prosecution rates for individuals who would commit a new offence if they were prosecuted. Here, prosecution falls evenly by racial group. These patterns suggest that the post-reform racial gap that we see in

⁵⁵Using the bounds on prosecution rates in Figure B22 to construct average discrimination conditional on prosecuted outcomes following Equation 3 will not yield the same estimates as the main analysis, which plugs the bounds for the average prosecuted outcomes directly into the expression for our main object of interest, the average period-specific racial gap, Δ_z . The two approaches involve computing averages and minima/maxima in different orders, which will produce numerically different results because minimum/maximum are not linear functions. See Section 3 for additional details.

Figure 12 is concentrated among individuals who would not commit an offence if prosecuted.

These patterns also provide suggestive evidence that prosecution is targeted based on the potential outcomes of defendants. Specifically, we see that prosecutors are less likely to prosecute individuals who **would** commit a new offence if prosecuted. To see this, compare the pre-reform prosecution rates for defendants who **would not** commit an offence if prosecuted (first two bounds in Panel (a)) to the pre-reform prosecution rates for those who **would** commit an offence if prosecuted (first two bounds in Panel (b)). 93%–100% of defendants of either race who would **would not** commit a new offence if prosecuted are being prosecuted, while the same is true for 75.1%–89.8% of defendants who **would** commit a new offence if prosecuted. This behavior is true in the post-reform period as well. After the reform, 74.7%–83.6% of defendants of either race who would **would not** commit a new offence if prosecuted are being prosecuted, while the same is true for 49.9%–62.8% of defendants who **would** commit a new offence if prosecuted.

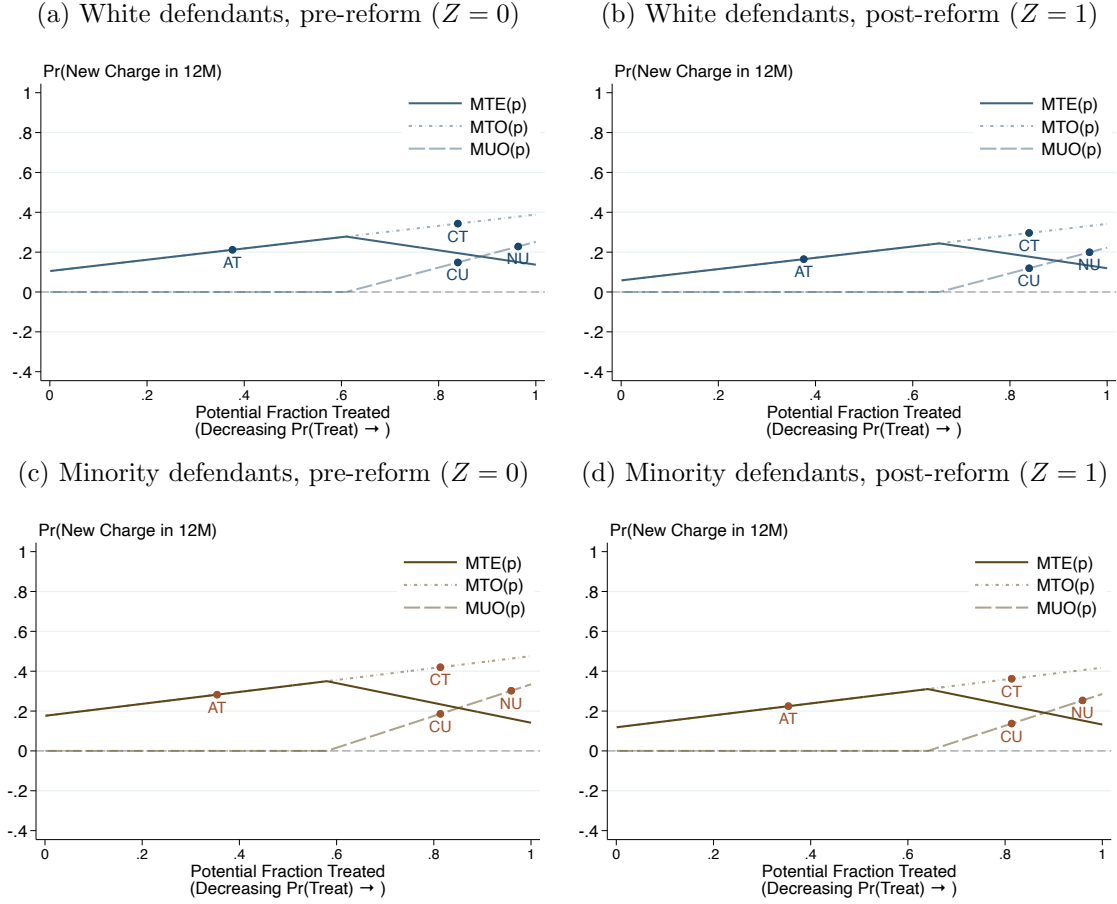
This is suggestive evidence that prosecutors are less willing to prosecute cases that would result in detrimental outcomes for defendants. To investigate this, we compare prosecution rates for defendants who would have had the same treatment effect of prosecution, following Equation 8. As discussed in Section 3, this exercise 1) requires restricting the distribution of treatment effects and 2) also bounding the treatment effect on the treated. To address 1), we assume that prosecution can either induce more crime (i.e., be criminogenic) or have no impact.

This rules out that prosecution can reduce future criminal activity, which is almost surely not satisfied at the individual-level in the population. However, violations of this assumption are likely small in this context. The literature on the deterrence effects of punishment typically finds small effects that mostly operate through incapacitation (e.g., jail), which is uncommon in our context of misdemeanor cases in Washington (Chalfin and McCrary, 2017). To examine the distribution of treatment effects in our context, we identify the marginal treatment effect (MTE) function under an auxiliary assumption of linearity in the relationship between likelihood of prosecution and potential outcomes.⁵⁶ Figure B23 shows that the MTE function in our context is always positive (i.e., increasing future criminal activity), which suggests that prosecution does not reduce future criminal activity for many people in this setting. Finally, since the treatment effect of prosecution is a function of the re-offence outcomes if dismissed, we need to make the same assumption (A3) of parallel trends in re-offence outcomes if dismissed as in the previous subsection to account for time trends in re-offence outcomes if dismissed.

Under these assumptions, Figure B24 shows bounds of prosecution rates separately for defendants where prosecution has no impact (Panel (a)) and where prosecution would be detrimental by inducing future criminal activity (Panel (b)). The bounds are much wider here, given the additional objects that we have to bound here. Before the reform, 90.3% – 98.1% of cases where prosecution would have no impact on future criminal activity were being prosecuted, while the same is true for 59.2%– 96.4% of cases where prosecution would be harmful. After the reform, 69.9% – 81.9% of

⁵⁶ As described in the main text, this assumption results in values for the marginal treated and untreated outcomes that lie outside the support of the potential outcomes (i.e., between 0 and 1). For this exercise, we constrain values of the marginal treated and untreated outcomes that are negative to be zero.

Figure B23: Marginal treatment response functions for prosecution

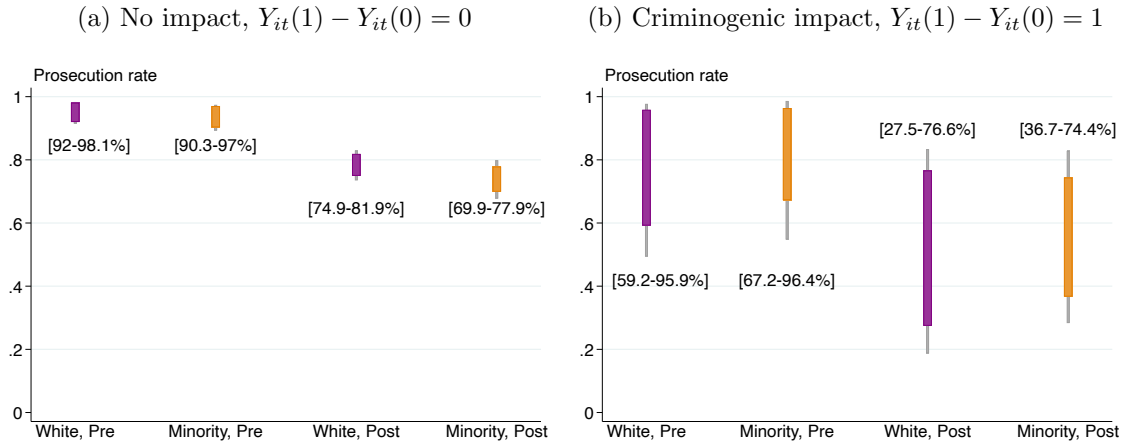


Note: This figure displays the marginal treatment response functions (Mogstad, Santos, and Torgovitsky, 2018) for prosecution. The treatment is prosecution and the outcome is whether an individual is charged with a new offence 12M after disposition. $MTO(p)$, $MUO(p)$ and $MTE(p)$ represent the marginal treated outcome, marginal untreated outcome and marginal treatment effect functions respectively. These are identified by assuming a linear relationship between potential outcomes of always takers ('AT'), compliers ('CT') and never takers ('NT') and their treatment propensities. Since $MTO(p)$ and $MUO(p)$ should lie within the support of the outcome (i.e., between 0 and 1), we constrain values of $MTO(p)$ and $MUO(p)$ that are negative to be zero. Lower values of the x-axis denote individuals who are more likely to be prosecuted.

cases where prosecution would have no impact on future criminal activity were being prosecuted, while the same is true for 27.5%– 76.6% of cases where prosecution would be harmful.

Since these bounds overlap, we cannot rule out that the prosecution rates are the same between defendants who would and would not be harmed by prosecution. However, given that the region of overlap is small, we interpret this as suggestive evidence that prosecutors may have been less likely to prosecute cases where it is likely to be criminogenic. This type of targeting behavior is consistent with recent work showing that prosecutors have some information about potential outcomes of cases and may choose not to prosecute defendants who may have higher risk of future contact with the criminal legal system (Agan, Doleac, and Harvey, 2023; Harrington, Murdock III, and Shaffer, 2023).

Figure B24: Prosecution rates, conditional on treatment effect of prosecution (π_{zry})



Note: This figure presents bounds on the average prosecution rates for each race group and time period, conditional on the treatment effect of prosecution using the approach described in Section 3. The outcome is whether an individual is charged with a new offence 12M after disposition. Confidence intervals are for the true parameter and are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Appendix C Methodological Appendix

C.1 Alternative approaches to estimate change in discrimination

Denote the change in discrimination due to a reform by $\Delta_{\text{change}} = \Delta_1 - \Delta_0$, following the definition of Δ_z in Definition 2. For simplicity, consider that the potential outcomes are binary. The observational analogue to quantifying how an intervention affected group gaps in treatment might be to estimate the group gap in treatment responses to the intervention, defined in Definition 3: e.g., by estimating the following regressions:

$$\begin{aligned} D_i &= \alpha_w + \beta_w Z_i + \varepsilon_{iw}, \text{ if } R_i = w \\ D_i &= \alpha_m + \beta_m Z_i + \varepsilon_{ib}, \text{ if } R_i = m \end{aligned}$$

Definition 3. Observed change in group treatment gaps due to policy reform (Δ_{obs})

$$\Delta_{\text{obs}} \equiv \beta_w - \beta_m, \text{ where } \beta_r = E[D_i|Z = 1, R_i = r] - E[D_i|Z = 0, R_i = r] \quad (11)$$

We are interested in whether the observed change in treatment responses coincides with the change in discrimination among individuals with identical treated potential outcomes. First, note that each expectation in Definition 3 is a weighted average of treatment rates for individuals with each potential outcome, where the weights are the prevalence of each binary value of the treated outcome. Equation 12 shows this, where $\pi_{zry} \equiv E[D_i|Z = z, R_i = r, Y_i(1) = y]$. The third and fourth lines follow from the fact that $Y_i(1) \perp Z$, since Z is random.

$$\begin{aligned} E[D_i|Z = z, R_i = r] &= E[Y_i(1) = 1|Z = z, R_i = r]E[D_i|Z = z, R_i = r, Y_i(1) = 1] \\ &\quad + E[Y_i(1) = 0|Z = z, R_i = r]E[D_i|Z = z, R_i = r, Y_i(1) = 0] \\ &= E[Y_i(1) = 1|R_i = r]E[D_i|Z = z, R_i = r, Y_i(1) = 1] \\ &\quad + E[Y_i(1) = 0|R_i = r]E[D_i|Z = z, R_i = r, Y_i(1) = 0] \\ \implies E[D_i|Z = z, R_i = r] &= Pr(Y_i(1) = 1|R_i = r)\pi_{zr1} + (1 - Pr(Y_i(1) = 1|R_i = r))\pi_{zr0} \end{aligned} \quad (12)$$

Plugging this into Definition 3, we can rewrite the observed change (Δ_{obs}) in terms of these group- and outcome-specific treatment averages:

$$\begin{aligned} \Delta_{\text{obs}} &= [(\mu_w\pi_{1w1} + (1 - \mu_w)\pi_{1w0}) - (\mu_w\pi_{0w1} + (1 - \mu_w)\pi_{0w0})] \\ &\quad - [(\mu_m\pi_{1m1} + (1 - \mu_m)\pi_{1m0}) - (\mu_m\pi_{0m1} + (1 - \mu_m)\pi_{0m0})] \end{aligned} \quad (13)$$

Similarly, Equation 14 rewrites the change in discrimination as a function of group- and outcome-specific treatment averages:

$$\begin{aligned}
\Delta_{\text{change}} &= Pr(Y_i(1) = 1) \underbrace{[\Delta_{11} - \Delta_{01}]}_{\text{Change, } Y_i(1) = 1} + (1 - Pr(Y_i(1) = 1)) \underbrace{[\Delta_{10} - \Delta_{00}]}_{\text{Change, } Y_i(1) = 0} \\
&= \underbrace{[Pr(Y_i(1) = 1)(\pi_{1w1} - \pi_{1m1}) + (1 - Pr(Y_i(1) = 1))(\pi_{1w0} - \pi_{1m0})]}_{\text{Gap when } Z=1} \\
&\quad - \underbrace{[Pr(Y_i(1) = 1)(\pi_{0w1} - \pi_{0m1}) + (1 - Pr(Y_i(1) = 1))(\pi_{0w0} - \pi_{0m0})]}_{\text{Gap when } Z=0}
\end{aligned} \tag{14}$$

Comparing Equation 13 and Equation 14, there are only 2 cases in which $\Delta_{\text{change}} = \Delta_{\text{obs}}$:

Case 1. $Y_i(1)$ is similar across groups: $Cov(Y_i(1), R_i) = 0 \implies Pr(Y_i(1) = 1 | R_i = r) = Pr(Y_i(1) = 1) \forall r \in R_i$

Case 2. Group-specific policy-induced responses are constant across $Y_i(1)$: $\pi_{1r1} - \pi_{0r1} = \pi_{1r0} - \pi_{0r0} = \theta_r$

The following shows how $\Delta_{\text{change}} = \Delta_{\text{obs}}$ under the described conditions. We will consider each case in turn.

Case 1

Consider that groups are similar on unobservables. Then, substituting $Pr(Y_i(1) = 1)$ for each $Pr(Y_i(1) = 1 | R_i = r)$ in Equation 13, we have:

$$\begin{aligned}
\Delta_{\text{obs}} &= [(Pr(Y_i(1) = 1)\pi_{1w1} + (1 - Pr(Y_i(1) = 1))\pi_{1w0}) - (Pr(Y_i(1) = 1)\pi_{0w1} + (1 - Pr(Y_i(1) = 1))\pi_{0w0})] \\
&\quad - [(Pr(Y_i(1) = 1)\pi_{1m1} + (1 - Pr(Y_i(1) = 1))\pi_{1m0}) - (Pr(Y_i(1) = 1)\pi_{0m1} + (1 - Pr(Y_i(1) = 1))\pi_{0m0})] \\
&= Pr(Y_i(1) = 1)[(\pi_{1w1} - \pi_{0w1}) - (\pi_{1m1} - \pi_{0m1})] + (1 - Pr(Y_i(1) = 1))[(\pi_{1w0} - \pi_{0w0}) - (\pi_{1m0} - \pi_{0m0})] \\
&= \Delta_{\text{change}}
\end{aligned}$$

Case 2

Allow groups to differ on unobservables. However, assume that the policy-induced treatment response for each group is constant across constant across $Y_i(1)$: $\pi_{1r1} - \pi_{0r1} = \pi_{1r0} - \pi_{0r0} = \theta_r$. Reorganizing Equation 13 to group the policy-induced treatment response terms by race and potential outcome level:

$$\begin{aligned}
\Delta_{\text{obs}} &= [Pr(Y_i(1) = 1 | R_i = w)(\pi_{1w1} - \pi_{0w1}) + (1 - Pr(Y_i(1) = 1 | R_i = w))(\pi_{1w0} - \pi_{0w0})] \\
&\quad - [Pr(Y_i(1) = 1 | R_i = m)(\pi_{1m1} - \pi_{0m1}) + (1 - Pr(Y_i(1) = 1 | R_i = m))(\pi_{1m0} - \pi_{0m0})] \\
&= \underbrace{\theta_w - \theta_m}_{\text{Gap in potential outcome-invariant responses}}
\end{aligned}$$

Substituting θ_r for $\pi_{1ry} - \pi_{0ry}$ in Equation 14, we see that $\Delta_{\text{change}} = \Delta_{\text{obs}}$.

$$\begin{aligned}\Delta &= Pr(Y_i(1) = 1)[\theta_w - \theta_m] + (1 - Pr(Y_i(1) = 1))[\theta_w - \theta_m] \\ &= \theta_w - \theta_m = \Delta_{\text{obs}}\end{aligned}$$

C.2 Point identifying discrimination with linear MTRs

We first sketch a simple model of selection. Individuals are treated if the benefit of treatment, $p_i(Y_i(1), Y_i(0), Z)$, outweighs the cost. Let Z be a binary instrument that shifts the benefit of treatment. $p_i(Y_i(1), Y_i(0), Z)$ can also be interpreted as an individual's treatment propensity, and can be normalized such that $p_i(Y_i(1), Y_i(0), Z) \in [0, 1]$. $u_i \in U[0, 1]$ is a unidimensional measure summarizing possibly multiple factors that determine an individual's cost of treatment. Given the IV assumptions listed in Section 2, $Y_i(D_i)$ and u_i are unaffected by Z . Consolidating this notation, individual i is treated if $D_i = \mathbb{I}[p_i(Y_i(1), Y_i(0), Z) \geq u_i]$.

Returning to the discussion of always takers (A), compliers (C) and never takers (N) in Section 3, assume that always takers have lower cost of treatment than compliers, who in turn have lower cost of treatment than never takers, $u_A \leq u_C \leq u_N$ (Angrist, Imbens, and Rubin, 1996).⁵⁷ Assuming that the relationship between treatment propensity and treated/untreated potential outcomes is linear, Equation 15 describes the expression for each marginal treatment response function, where $\bar{Y}_{(\cdot)}$ represents the average treated/untreated outcome for always takers, compliers or never takers (Brinch, Mogstad, and Wiswall, 2017; Mogstad, Santos, and Torgovitsky, 2018; Kowalski, 2023b). The remaining steps to estimate discrimination follows Section 3, except that we estimate average treated or untreated potential outcomes by integrating $MTO(p)$ or $MUO(p)$ over the full support of the treatment propensity. As a result, we obtain point estimates for the average treated/untreated outcomes and discrimination estimands.

$$\begin{aligned}MTO(p) &\equiv E[Y_i(1)|p = u_i] = \bar{Y}_{T,A} - \frac{p_A}{p_C} (\bar{Y}_{T,AC} - \bar{Y}_{T,A}) + \frac{2}{p_C} (\bar{Y}_{T,AC} - \bar{Y}_{T,A}) \times p \\ MUO(p) &\equiv E[Y_i(0)|p = u_i] = \frac{(2 - p_N)\bar{Y}_{U,NC} - (1 + p_A)\bar{Y}_{U,N}}{p_C} + \frac{2}{p_C} (\bar{Y}_{U,N} - \bar{Y}_{U,NC}) \times p \\ MTE(p) &\equiv E[Y_i(1) - Y_i(0)|p = u_i] = MTO(p) - MUO(p)\end{aligned}\tag{15}$$

We briefly demonstrate point identifying discrimination using the context of racial discrimination in incarceration decisions with publicly-available case-level records from Bexar County Criminal District (felony) Courts. We use a large reform meant to reduce overcrowding in Texas jails (SB 1067 in 1994). The goal of the reform was to reduce the burden on correctional facilities by limiting the incarceration rates for low-level offenders. The reform created a new category of felony: the state jail felony (SB 1067 Article 1, Subchapter C, §12.35) which reduced the punishment associated

⁵⁷Vytlacil (2002) demonstrates how latent index selection models coincide with the potential outcomes framework of Imbens and Angrist (1994).

with a wide range of common offences, including many property and drug crimes. These provisions only applied to offences committed on or after September 1, 1994.⁵⁸

Figure C1 validates this natural experiment separately for white and minority defendants. Panels a) and b) show that the reform resulted in a 6pp (7%) increase in non-incarceration among white defendants and a 14pp (20%) increase among minority defendants. Panels c) and d) demonstrate that future criminal activity falls by 3.1pp for white defendants (−32.6%) and increases by 3.8pp for minority defendants (29%), although the former estimate is imprecise. Panels e) and f) show that a summary measure of the baseline characteristics of defendants is smooth around this date cut-off.

Given that the reform is a valid natural experiment, we apply it to estimate marginal treatment response functions as described above. We define treatment as $D_i = 1$ if an individual is not incarcerated (referred to as ‘released’ henceforth) and $D_i = 0$ if incarcerated. If an individual is released, we observe their treated re-offence outcome $Y_i(1)$. Here, we define $Y_i(1) = 1$ if an individual commits a new offence in the 12 months after they are released. Finally, while we assessed the validity of the natural experiment using regression discontinuity techniques, we parametrize Z as a binary instrument for simplicity: $Z = 1$ if an individual committed an offence after September 1, 1994.⁵⁹

Figure C2 plots the estimated race-specific marginal treated outcome functions, $MTO_r(p)$ and Table C1 integrates these functions to estimate the average outcome that would be realized if everyone was released. The point estimates suggest meaningful differences in underlying potential outcomes. 9.7% of white defendants would re-offend if released, while 17.7% of minority defendants would, although these difference are not significant.

Table C1: Average re-offence estimates (p.p.)

	Average (1)	White (2)	Minority (3)
μ	0.155	0.097	0.177
95% CI	[0.121,0.188]	[0.011,0.180]	[0.143,0.211]

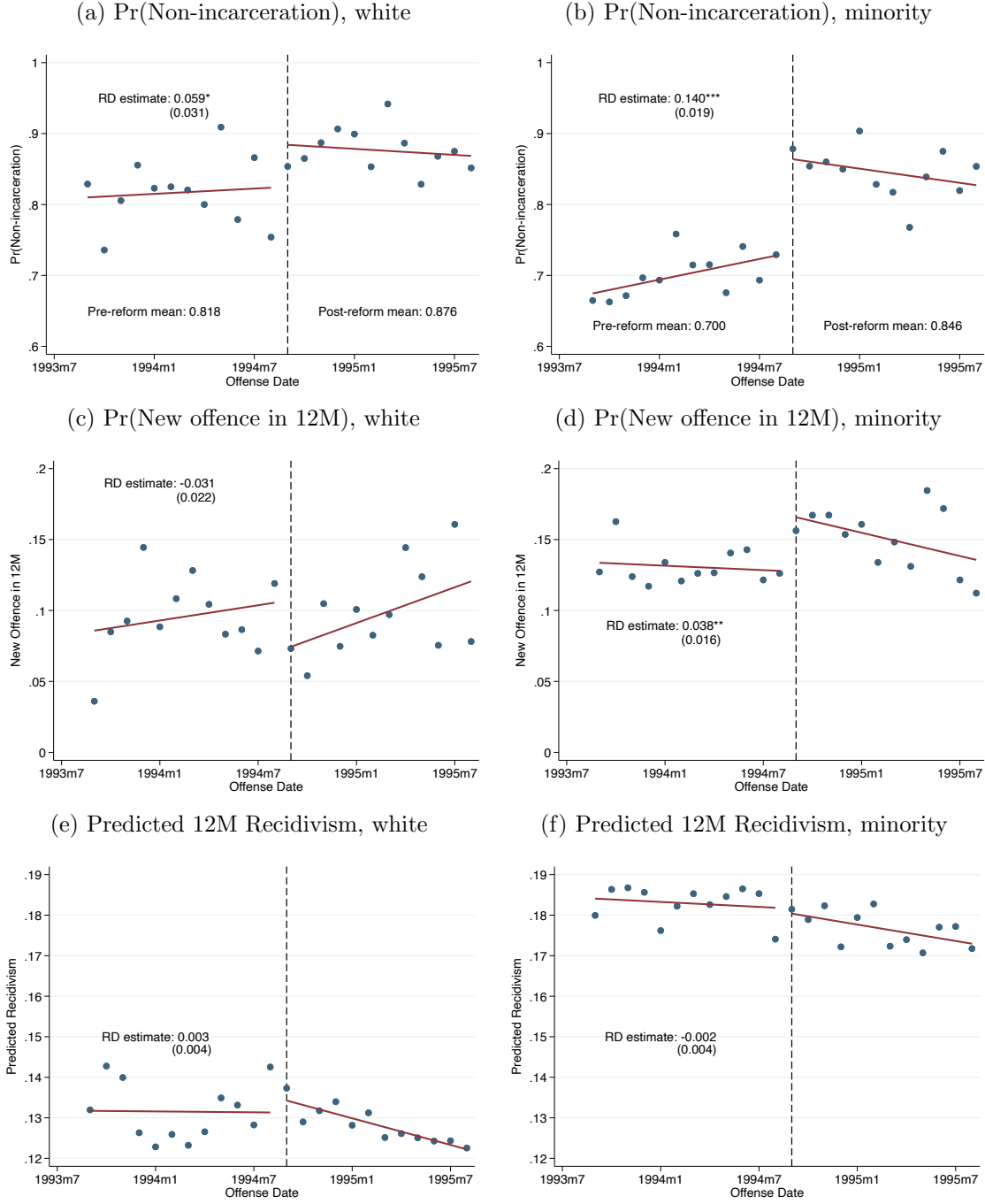
Note: This table presents estimates of the average treated outcome obtained using the approach described in Section 3, separately by race. The treatment is non-incarceration and the treated outcome is whether an individual is charged with a new offence 12M after disposition. Confidence intervals are bootstrapped using 1,000 replications and a Bayesian bootstrap.

Following, Equation 3, Table C2 displays point estimates of racial discrimination in non-incarceration decisions that condition on re-offence outcomes if not incarcerated. Prior to the reform, white individuals were 12.3pp more likely to be released than minority individuals and the reform significantly narrowed this disparity. After the reform, release rates were 3.4pp higher for White defendants, a 8.9pp reduction.

⁵⁸Mueller-Smith and Schnepel (2021) use data from Harris County, TX to study a related aspect of the same legislation, which changed the incentives to offer deferred adjudication.

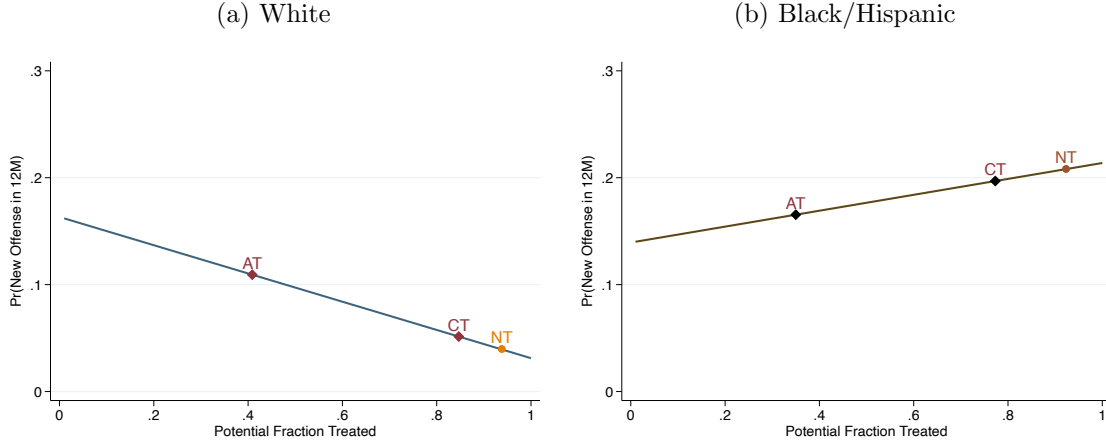
⁵⁹We alternatively could have followed the implementation in Section 4. However, given the general lack of trends in treatment and in re-offence outcomes here, the implementation are unlikely to meaningfully differ.

Figure C1: Linearity application: validating natural experiment



Note: Each Panel presents RD estimates from regressions of the form $Y_i = \alpha + \beta \mathbf{1}(T_i > t) + \delta_1 T_i + \delta_2 \mathbf{1}(T_i > t) \times T_i + \varepsilon_i$, where T_i denotes the running variable, and t denotes the cut-off date of September 1, 1994. Sample includes all felony defendants who committed an offence in a year around the cut-off date. The lines of best fit are estimated on the monthly averages, represented by the blue dots. Incarceration is defined as serving an incarceration sentence. Predicted recidivism is computed by estimating $\mathbf{1}(\text{New Offence})_i = \alpha + \beta X_i + \nu_i$ using pre-reform data, and excluding the RD sample. These coefficients are then used to predict the probability of re-offending for the RD sample. X includes: indicators for race, offence type, felony category, gender, age, criminal history and neighbourhood characteristics.

Figure C2: Average re-offence extrapolation by race



Note: Marginal treated outcome curves identified using $Z = t \geq 1$ (September 1, 1994) as a binary instrument. The outcome used is whether an individual commits a new offence within 1 year, if not incarcerated. “Potential fraction treated” refers to the fraction of the population that is treated. Lower values denote individuals who are more likely to be released. As we move from 0 to 1, the fraction increases as individuals relatively less likely to be released are released. ‘AT’, ‘CT’, and ‘NT’ denote the estimated treated outcomes for always takers compliers and never takers respectively. The diamonds reflect outcomes of the median individual in that group.

Table C2: Estimated disparities (p.p.)

	Pre ($Z = 0$) (1)	Post ($Z = 1$) (2)	Change (3)
Δ	0.123	0.034	-0.089
95% CI	[0.084, 0.447]	[0.003, 0.276]	[-0.170, -0.050]

Note: This figure presents the average disparities in each time period, conditional on treated potential outcomes, using the approach described in Section 3. The treatment is non-incarceration and the treated outcome, denoted by $Y_i(1)$, is whether an individual is charged with a new offence 12M after disposition. Confidence intervals are bootstrapped using 1,000 replications and a Bayesian bootstrap.

C.3 Estimating average potential outcomes with difference-in-difference

This section describes conditions under which we can non-parametrically bound average potential outcomes and average treatment effects in DiD settings with individual-level treatment non-compliance and heterogeneity in potential outcomes. The approach involves viewing the policy adoption as randomly assigned within the affected county. However, the estimation of causal effects is confounded by the effects of time, which are correlated with the policy adoption. We use changes in the unaffected control county to purge these effects of time. Our approach is similar to “time-corrected” Wald approach to estimate the LATE from recent work (De Chaisemartin and D’Haultfœuille, 2018). However, we require stronger assumptions to identify average potential outcomes and treatment effects for those who are not compliers.

We start with the following notation:

- $T \in \{0, 1\}$: Denotes periods before (pre) and after (post) a policy

- $G \in \{0, 1\}$: 1 if the county adopts the policy in $T = 1$, 0 if not.
- $Z \equiv T \times G \in \{0, 1\}$: This is the binary instrument
- $D_i(g, z) \in \{0, 1\}$: Whether an **individual** takes up treatment or not.⁶⁰
- $Y_{it}(d, g)$: Potential outcomes, given the time period, their treatment state and the county they are in.
- Refer to always takers, compliers and never takers as “compliance groups”

We make the following assumptions, many of which are typically assumed in IV implementations.

Assumption 1. First stage: $Pr(D_i(g, Z = 1)) > Pr(D_i(g, Z = 0)) \forall g$

Assumption 2. Independence and exclusion: $(Y_{it}(1, g), Y_{it}(0, g), D_i(g, 1), D_i(g, 0)) \perp Z | g$.

This implies that within each county, the instrument is random and only affects outcomes via changes in treatment status (Imbens and Angrist, 1994). However, this allows for a) potential outcomes to differ across counties and b) time-varying factors to directly affect potential outcomes.

Assumption 3. No spillovers: The potential outcomes of individual i are unrelated to the treatment status of other individuals (Angrist, Imbens, and Rubin, 1996).

Assumption 4. IV monotonicity: $D_i(g, 1) \geq D_i(g, 0) \forall g$

This allows the instrument to (weakly) shift individuals in only one direction across treatment contrasts and does not allow secular trends to change treatment status of individuals. Together, this means that only the following shifts between treatment contrasts are permitted:

1. $D_i(g, z) = 1 \forall z$: These are always takers in group g
2. $D_i(g, z) = 0 \forall z$: These are never takers in group g
3. $D_i(g, 1) = 1$ and $D_i(g, 0) = 0$: These are compliers in group g , shifted by the instrument

Finally, we make an additional assumption that is in the spirit of parallel trends assumptions, but is not typically made in IV settings or DiD estimation:⁶¹

⁶⁰Note that this allows individuals in either county to be treated both before and after the policy, unlike county-level treatment in typical DiD.

⁶¹This is similar to the assumption underlying the “time-corrected” Wald estimand in De Chaisemartin and D’Haultfœuille (2018). There, the treated (untreated) potential outcomes for those treated (not treated) in the pre-period are the same across group. This is enough to identify the LATE, but does not allow us to identify the average potential outcomes of each compliance group separately. This is because it pins down time trends in a) treated outcomes for always takers and b) an average of untreated outcomes for both never takers and compliers. This does not pin down time trends for compliers specifically without further assumptions.

Assumption 5. Parallel trends in potential outcomes: This assumes that i) the average change in treated outcomes is the same for always takers and compliers and is independent of county and ii) the average change in untreated outcomes is the same for never takers and compliers and is independent of county. This restricts the effects of time on potential outcomes to be constant across subsets of compliance groups, but not all of them, and does not force the effects of time to be identical across individuals.

$$\begin{aligned} E[Y_{i1}(1, g) - Y_0(1, g)|g, \text{Always taker}] &= E[Y_{i1}(1, g) - Y_0(1, g)|g, \text{Complier}] \text{ and } \perp g \\ E[Y_{i1}(0, g) - Y_0(0, g)|g, \text{Never taker}] &= E[Y_{i1}(0, g) - Y_0(0, g)|g, \text{Complier}] \text{ and } \perp g \end{aligned}$$

We now show how, under these assumptions, we can identify the proportions and average treated/untreated outcomes of always takers (A), never takers (N) and compliers (C) in the $G = 1$ county.

Given this setup, there are no shifts in treatment status due to secular changes. Hence we have that the proportion of always takers (p_A), compliers (p_C) and never takers (p_N) in $G = 1$ are directly observed in the data for $G = 1$.

$$\begin{aligned} p_A &= E[D_i|G = 1, T = 0] \\ p_N &= 1 - (E[D_i|G = 1, T = 1]) \\ p_C &= 1 - (p_A + p_N) \end{aligned} \tag{16}$$

However, since common time trends can affect potential outcomes, the treated and untreated potential outcomes for each of these groups is not directly observed. To see this, recall that in settings where a binary instrument Z increases treatment take-up, the outcomes of individuals who are treated when $Z = 0$ identifies the treated outcomes for always takers. Equation 17 shows that if we try to estimate the treated outcomes for always takers in $G = 1$ using pre-period data (since $Z = 0 \ \& \ G = 1 \implies T = 0$), we only recover treated outcomes for always takers in the pre-period. The difference between this and the treated outcomes for always takers in the post-period is the trend in treated potential outcomes, θ_1 (second line of Equation 17).

$$\begin{aligned} E[Y_i|D_i = 1, G = 1, Z = 0] &= E[Y_i|D_i = 1, G = 1, T = 0] = E[Y_{i0}(1, 1)|A, G = 1] \\ \underbrace{E[Y_{i1}(1, 1)|A, G = 1]}_{\text{Unobserved}} &= \underbrace{E[Y_{i0}(1, 1)|A, G = 1]}_{\text{Observed}} + \underbrace{\theta_1}_{\text{Unobserved}} \end{aligned} \tag{17}$$

Equation 18 makes the same point for the untreated outcomes for never takers. In settings where a binary instrument Z increases treatment take-up, the outcomes of individuals who are not treated when $Z = 1$ identifies the untreated outcomes for never takers. Here, the outcomes of individuals who are not treated in the post-period only identifies the untreated outcomes for

never takers in the post-period. Similarly, the difference between this and the untreated outcomes for never takers in the pre-period is the trend in untreated potential outcomes, θ_0 (second line of Equation 18).

$$\begin{aligned}
E[Y_i|D_i = 0, G = 1, Z = 1] &= E[Y_i|D_i = 0, G = 1, T = 1] = E[Y_{i1}(0, 1)|N, G = 1] \\
\underbrace{E[Y_{i0}(0, 1)|N, G = 1]}_{\text{Unobserved}} &= \underbrace{E[Y_{i1}(0, 1)|N, G = 1]}_{\text{Observed}} - \underbrace{\theta_0}_{\text{Unobserved}}
\end{aligned} \tag{18}$$

We can use Assumption 5 to identify the time trends in treated and untreated outcomes in $G = 1$ (θ_1 & θ_0) using the change over time in $G = 0$. Starting with treated outcomes, note that the only individuals who would be treated in the control county are always takers. Hence the average change in treated outcomes in $G = 0$ identifies the time trend for always takers in $G = 1$, since Assumption 5 states that time trend in potential treated outcomes for always takers are identical across counties and is equal to the time trend for compliers (see Equation 19).

$$\begin{aligned}
\theta_1 &= E[Y_{i1}(1, 1) - Y_{i0}(1, 1)|G = 1, A] = E[Y_{i1}(1, 1) - Y_{i0}(1, 1)|G = 1, C] \\
&= E[Y_{i1}(1, 0) - Y_{i0}(1, 0)|G = 0]
\end{aligned} \tag{19}$$

Similarly, the individuals who are untreated in the control county, $G = 0$, consist of compliers and never takers. From Assumption 5, the change in untreated outcomes for never takers and compliers are identical to each other, which means the average change in untreated outcomes in $G = 0$ equals the average change in untreated outcomes for never takers in $G = 0$. Additionally, Assumption 5 states that the time trend in untreated outcomes for never takers is identical across counties, which allows us to identify the time trend in untreated outcomes for never takers in $G = 1$ (see Equation 20).

$$\begin{aligned}
\theta_0 &= E[Y_{i1}(0, 1) - Y_{i0}(0, 1)|G = 1, N] = E[Y_{i1}(0, 1) - Y_{i0}(0, 1)|G = 1, C] \\
&= E[Y_{i1}(0, 0) - Y_{i0}(0, 0)|G = 0]
\end{aligned} \tag{20}$$

Equation 21 restates this by combining this with Equations 17 and 18, to show how the time trend in the treated outcomes of always takers and untreated potential outcomes of never takers in $G = 1$ can be identified using the aggregate changes in treated and untreated potential outcomes in the control county, $G = 0$.

$$\begin{aligned}
E[Y_{i1}(1, 1)|A, G = 1] &= E[Y_{i0}(1, 1)|A, G = 1] + \theta_1 \\
&= E[Y_{i0}(1, 1)|A, G = 1] + E[Y_{i1}(1, 0) - Y_{i0}(1, 0)|G = 0]
\end{aligned} \tag{21}$$

$$\begin{aligned}
E[Y_{i0}(0, 1)|N, G = 1] &= E[Y_{i1}(0, 1)|N, G = 1] - \theta_0 \\
&= E[Y_{i1}(0, 1)|N, G = 1] - E[Y_{i1}(0, 0) - Y_{i0}(0, 0)|G = 0]
\end{aligned}$$

We now have the treated outcomes for always takers and the untreated outcomes for never takers from $G = 1$ in both periods. We can use this information with other observed moments in the data to estimate the treated and untreated outcomes for compliers (Imbens and Rubin, 1997).

Starting with treated outcomes, the first line of Equation 22 notes that the observed outcomes among treated individuals in period $T = 1$ is a weighted average of treated outcomes for always takers and compliers in $T = 1$. Rearranging this expression, the second line shows that the treated outcomes for compliers in $T = 1$, $E[Y_{i1}(1, 1)|C, G = 1]$, is a function of moments that we can estimate. $E[Y_{i1}(1, 1)|A, G = 1]$ is obtained from Equation 21, $E[Y_i|D_i = 1, G = 1, T = 1]$ is a sample average, and each of the proportions is obtained using Equation 16.

$$\begin{aligned}
E[Y_i|D_i = 1, G = 1, T = 1] &= \frac{p_A E[Y_{i1}(1, 1)|A, G = 1] + p_C E[Y_{i1}(1, 1)|C, G = 1]}{p_A + p_C} \\
E[Y_{i1}(1, 1)|C, G = 1] &= \frac{(p_A + p_C) E[Y_i|D_i = 1, G = 1, T = 1] - p_A E[Y_{i1}(1, 1)|A, G = 1]}{p_C}
\end{aligned} \tag{22}$$

We can estimate untreated outcomes for compliers in a similar way. The first line of Equation 23 shows that the observed outcomes among untreated individuals in period $T = 0$ is a weighted average of untreated outcomes for never takers and compliers in $T = 0$. Rearranging this expression, the second line shows that the untreated outcomes for compliers in $T = 0$, $E[Y_{i0}(0, 1)|C, G = 1]$, is a function of moments that we can estimate. $E[Y_{i0}(1, 1)|N, G = 1]$ is obtained from Equation 21, $E[Y_i|D_i = 0, G = 1, T = 0]$ is a sample average, and each of the proportions is obtained using Equation 16.

$$\begin{aligned}
E[Y_i|D_i = 0, G = 1, T = 0] &= \frac{p_N E[Y_{i0}(0, 1)|N, G = 1] + p_C E[Y_{i0}(0, 1)|C, G = 1]}{p_N + p_C} \\
E[Y_{i0}(0, 1)|C, G = 1] &= \frac{(p_N + p_C) E[Y_i|D_i = 0, G = 1, T = 0] - p_N E[Y_{i0}(0, 1)|N, G = 1]}{p_C}
\end{aligned} \tag{23}$$

As a result, we have identified the following objects:

- Treated outcomes in each period for always takers

- Untreated outcomes in each period for never takers
- Treated outcomes in $T = 1$ for compliers
- Untreated outcomes in $T = 0$ for compliers

We are missing 2 objects: Treated outcomes in $T = 0$ for compliers and untreated outcomes in $T = 1$ for compliers. Assumption 5 allows us to recover this, since it implies the time trend in treated/untreated potential outcomes of each compliance group in $G = 1$ can be identified using the aggregate changes in treated/untreated potential outcomes in the control county, $G = 0$.

$$\begin{aligned} E[Y_{i0}(1, 1)|C, G = 1] &= E[Y_{i1}(1, 1)|C, G = 1] - \theta_1 \\ E[Y_{i1}(0, 1)|C, G = 1] &= E[Y_{i0}(0, 1)|C, G = 1] + \theta_0 \end{aligned} \tag{24}$$

We now have average treated and untreated outcomes for each compliance group and in each period.

C.4 Bounds when conditioning on $Y_i(0)$ or $Y_i(1) - Y_i(0)$

Conditioning on $Y_i(0)$

Equation 25 shows how the share of individuals not treated, with a given untreated outcome (e.g., the dismissal rate for people with a specific outcome if dismissed) can be used to quantify the share of treated individuals with a specific untreated outcome, abstracting away from the period-specific notation Z . The first line subtracts the share of individuals not treated with a given untreated outcome from 1, where $\bar{D} = E[D_i|R_i = r]$, and where $E[D_i = 0|R_i = r, Y_i(0) = y]$ is rewritten in the same way as described in Equation 2. The third line uses the fact that the average untreated outcome observed if everyone was untreated is a weighted average of the untreated outcomes for the treated individuals and the untreated individuals: $E[Y_i(0) = y|R_i = r] = E[Y_i(0) = y|R_i = r, D_i = 1]\bar{D} + E[Y_i(0) = y|R_i = r, D_i = 0](1 - \bar{D})$. This recovers the share of treated individuals with a specific untreated outcome, described in Equation 7.

$$\begin{aligned} 1 - E[D_i = 0|R_i = r, Y_i(0) = y] &= 1 - \frac{E[Y_i(0) = y|R_i = r, D_i = 0] \times (1 - \bar{D})}{E[Y_i(0) = y|R_i = r]} \\ &= \frac{E[Y_i(0) = y|R_i = r] - E[Y_i(0) = y|R_i = r, D_i = 0] \times (1 - \bar{D})}{E[Y_i(0) = y|R_i = r]} \\ &= \frac{E[Y_i(0) = y|R_i = r, D_i = 1] \times \bar{D}}{E[Y_i(0) = y|R_i = r]} \\ &= E[D_i|R_i = r, Y_i(0) = y] \end{aligned} \tag{25}$$

Conditioning on $Y_i(1) - Y_i(0)$

The equation below reproduces Equation 8, where $\tau_i \equiv Y_i(1) - Y_i(0)$. The right hand side is a function of two partially identified objects (first term in numerator and denominator) and a point estimate (second term in numerator). The two partially identified objects are dependent – the denominator is a function of the first term in the numerator.

$$E[D_i|Z = z, R_i = r, \tau_i = y] = \frac{E[\tau_i = y|Z = z, R_i = r, D_i = 1] \times E[D_i|Z = z, R_i = r]}{E[\tau_i = y|R_i = r]}$$

We rewrite the treatment rate conditional on the treatment effect, omitting group conditioning for brevity and considering the case where the policy reform has taken effect, i.e. $Z = 1$. Here, we assume that $\tau_i \in \{0, 1\}$, because this assumption is required to identify this type of treatment rate, as described in Section 3.

$$\begin{aligned} E[D_i|Z = 1, \tau_i = 1] &= \frac{E[\tau_i|Z = z, D_i = 1] \times E[D_i|Z = z]}{E[\tau_i]} \\ &= \frac{(p_A E[\tau_i|A] + p_C E[\tau_i|C]) / (p_A + p_C)}{p_A E[\tau_i|A] + p_C E[\tau_i|C] + p_N E[\tau_i|N]} \times E[D_i|Z = 1] \end{aligned} \quad (26)$$

The average treatment effect on the treated is a function of the bounds on the treatment effect for always takers and the point estimated treatment effect for compliers. The denominator ($E[\tau_i]$) is a function of two partially identified objects, $E[\tau_i|A]$ and $E[\tau_i|N]$, since we never observe untreated outcomes for always takers or treated outcomes for never takers.

This implies that the treatment rate conditional on the treatment effect is of the form $y = f(p, q) = \frac{p \times r}{p + q}$, where r is a point estimate and the other quantities are bounds. We compute bounds for y by holding one partially identified object fixed at a time, evaluating the function at the extremes of the other partially identified object. That is, we take the minimum and maximum values of y over the following cases: $f(\underline{p}, \underline{q})$, $f(\underline{p}, \bar{q})$, $f(\bar{p}, \underline{q})$, $f(\bar{p}, \bar{q})$.

C.5 Inference for tests of overlapping bounds

Here we discuss how we test whether the average potential outcome bounds estimated for each group overlap. Let the true parameter of interest for each group be μ_r , where $r \in \{m, w\}$ denotes the group. Let the estimated bounds be $[\mu_{r,L}, \mu_{r,U}]$. The goal is to test whether $[\mu_{m,L}, \mu_{m,U}]$ and $[\mu_{w,L}, \mu_{w,U}]$ overlap.

We construct a set that denotes the difference between the upper bound for one group and the lower bound for another: $\mathbf{M}_d \equiv [\mu_{m,L} - \mu_{w,U}, \mu_{m,U} - \mu_{w,L}] = [\tilde{\mu}_L, \tilde{\mu}_U]$. Note that $0 \in \mathbf{M}_d$ only if the bounds for each race are overlapping. To see this, consider the following three cases:⁶²

⁶²There are 3 more cases if you switch m and w , but they yield the same conclusions. These conditions also hold if the intervals themselves contain 0.

Case 1. $[\mu_{m,L}, \mu_{m,U}]$ and $[\mu_{w,L}, \mu_{w,U}]$ are disjoint. E.g., $[\mu_{m,L}, \mu_{m,U}] = [0.5, 0.6]$ and $[\mu_{w,L}, \mu_{w,U}] = [0.2, 0.3]$. Then, $\mathbf{M_d} = [0.2, 0.4]$

Case 2. $[\mu_{m,L}, \mu_{m,U}]$ and $[\mu_{w,L}, \mu_{w,U}]$ overlap but one is not a subset of the other. E.g., $[\mu_{m,L}, \mu_{m,U}] = [0.25, 0.6]$ and $[\mu_{w,L}, \mu_{w,U}] = [0.2, 0.3]$. Then, $\mathbf{M_d} = [-0.05, 0.4]$

Case 3. $[\mu_{m,L}, \mu_{m,U}]$ is contained within $[\mu_{w,L}, \mu_{w,U}]$. E.g., $[\mu_{m,L}, \mu_{m,U}] = [0.2, 0.8]$ and $[\mu_{w,L}, \mu_{w,U}] = [0.3, 0.4]$. Then, $\mathbf{M_d} = [-0.2, 0.5]$

Our goal is to test the following null hypothesis: $H_0 : 0 \in \mathbf{M_d}$. We bootstrap the estimation of the bounds using a Bayesian bootstrap (Rubin, 1981), enforcing the weak monotonicity restriction implied by each bootstrap replication. For each replication, we construct the interval $\mathbf{M_d} \equiv [\mu_{m,L} - \mu_{w,U}, \mu_{m,U} - \mu_{w,L}] = [\tilde{\mu}_L, \tilde{\mu}_U]$. We then calculate a p -value as the share of the bootstrap replications in which $0 \in \mathbf{M_d}$, i.e., in which the bounds overlap.

C.6 Extrapolation using average potential outcomes identified at a RD cut-off

We can apply the average treated outcome estimates derived from information at the cut-off to adjust treatment rates in portions of the analysis sample that are away from the cut-off under certain assumptions. Let the analysis sample include the following values of the running variable (e.g., a test score): $s \in [\underline{s}, \bar{s}]$ and let s^* be the cut-off. Let D_i denote the treatment decision (e.g., whether student i is promoted) and Z denote whether a student is above or below the test-score cut-off. Finally, any assumptions discussed below will need to hold by subgroup.

Assume that the following hold (omitting subgroup notation here):

RD1: $D_i \perp s$ and $E[D_i|Z = 1, s^*] - E[D_i|Z = 0, s^*] = E[D_i|Z = 1, s] - E[D_i|Z = 0, s] \forall s \in [\underline{s}, \bar{s}]$

RD2: $E[Y_i(1)|s = s^*] = E[Y_i(1)|s < s^*] = E[Y_i(1)|s > s^*]$

Let us consider these assumption in the context of the application in Section 4. RD1 states that within the analysis window, the test score does not influence promotion decisions by itself – only the cut-off does. RD1 also assumes that the size of the first-stage would be the same in counterfactuals where the test score cut-off was placed elsewhere in the window. This ensures that the proportions of always takers, compliers and never takers identified at the cut-off are applicable to the wider window. RD2 assumes that the average promoted outcomes that would be realized if all students **at the cut-off** were promoted is equal to the average promoted outcomes if students elsewhere in the window were all promoted. In the simplest case, this would be satisfied if $Y_i(1)$ did not vary across s . These assumptions are stronger than those in typical approaches to extrapolate away from RD cut-offs. This is because the focus here is on extrapolating average potential outcomes rather than treatment effects (Cattaneo et al., 2021; Ricks, 2022).

In our setting, we fail to reject that running variable alone influences treatment rates, which is suggestive evidence that RD1 is not violated here. To assess whether RD2 is reasonable, note that we can split $E[Y_i(1)|s = s^*]$ into average treated outcomes for always takers, compliers and

never takers. Let $p_{(\cdot)}$ denote the proportion of always takers (A), compliers (C) or never takers (N). Consider the first part of the equality in RD2, which compares students at the cut-off to those below. RD2 implies that the equality in [Equation 27](#) must hold.

$$\begin{aligned}
E[Y_i(1)|s = s^*] &= E[Y_i(1)|s < s^*] \\
\implies p_A E[Y_i(1)|A, s = s^*] + p_C E[Y_i(1)|C, s = s^*] + p_N E[Y_i(1)|N, s = s^*] &= \\
p_A E[Y_i(1)|A, s < s^*] + p_C E[Y_i(1)|C, s < s^*] + p_N E[Y_i(1)|N, s < s^*] & \\
\implies p_C (E[Y_i(1)|C, s = s^*] - E[Y_i(1)|C, s < s^*]) + p_N (E[Y_i(1)|N, s = s^*] - E[Y_i(1)|N, s < s^*]) &= \\
= p_A (E[Y_i(1)|A, s < s^*] - E[Y_i(1)|A, s = s^*]) &
\end{aligned} \tag{27}$$

Whether this is a reasonable assumption is an empirical question. In [Figure 3](#), all individuals below the cut-off are always takers for promotion (they are being promoted despite being below the cut-off). Here, always takers below the cut-off clearly have lower treated outcomes than those at the cut-off, implying that always takers **below the cut-off** are less likely to be prepared for 4th grade than always takers **at the cut-off**. Mathematically, this means that the right hand side of final expression of [Equation 27](#) is negative. The only way for this assumption to hold with equality is for the left hand side to be sufficiently negative to offset this. However, that would imply that compliers and never takers **at the cut-off** are less prepared for 4th grade than compliers and never takers **below the cut-off**, which is at odds with reasonable models of selection into promotion. Comparing the average treated outcomes at the cut-off to that above the cut-off yields a similar conclusion.

If we are in a situation where these assumptions might be violated, it is useful to consider the direction of bias that arises from applying average potential outcomes identified at an RD cut-off to the entire sample. We introduce additional notation, assuming the potential outcomes are binary:

- True & estimated average treated outcome by group: $E[Y_i(1)|R_i = r] = \mu_r$ and $\hat{\mu}_r$
- True & estimated average treated outcome in population: $E[Y_i(1)] = \mu_r$ and $\hat{\mu}$
- $R_i \in \{h, l\}$

Following [Equation 3](#), we derive the bias in the period-, group- and outcome-specific treatment rates:

$$\begin{aligned}
\hat{\pi}_{zr1} &= \pi_{zr1} \left(\frac{\mu_r}{\hat{\mu}_r} \right) \\
\hat{\pi}_{zr0} &= \pi_{zr0} \left(\frac{1 - \mu_r}{1 - \hat{\mu}_r} \right) \\
\hat{\bar{\mu}} - \bar{\mu} &= p_h(\hat{\mu}_h - \mu_h) + p_l(\hat{\mu}_l - \mu_l)
\end{aligned} \tag{28}$$

Since μ_r and $1 - \mu_r$ are always positive (they represent shares of individuals with a given value of $Y_i(D_i)$), we sign the bias that results from biased estimates of μ_r . Consider that $\hat{\mu}_r > \mu_r$, which would be the case in the example above that extrapolates μ_r from the cut-off to below the cut-off. Equation 28 implies that i) $\hat{\pi}_{zr1} < \pi_{zr1}$, ii) $\hat{\pi}_{zr0} > \pi_{zr0}$. That is, applying information from the cut-off to below the cut-off in such a situation would lead one to i) underestimate the promotion rate of students who are ready for 4th grade and ii) overestimate the promotion rate of students who are not ready. If $\hat{\mu}_r > \mu_r$ for both groups, then iii) $\hat{\bar{\mu}} > \bar{\mu}$, i.e., one would overestimate the overall readiness for 4th grade in the population.

However, the implications for potential outcome-specific gaps below/above the cut-off (Δ_{zy}) and average gaps below/above the cut-off (Δ_z) are ambiguous. Recall that

$$\begin{aligned}
\Delta_{zy} &= \pi_{zhy} - \pi_{zly} \\
\Delta_z &= \bar{\mu} \Delta_{z1} + (1 - \bar{\mu}) \Delta_{z0}
\end{aligned}$$

Even if the estimates for π_{zhy} and π_{zly} are both biased in the same direction, the relative magnitudes of the bias in π_{zry} for each group will determine the overall bias in Δ_{zy} . Similarly, the impact on Δ_z is ambiguous since the estimates of Δ_{z1} and Δ_{z0} will be biased in different directions.