Using a Ratio Test to Estimate Racial Differences in Wrongful Conviction Rates

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Abstract: We show that under arguably plausible assumptions regarding the DNA exoneration process, in expectation, the *ratio* of DNA exoneration rates across races among defendants convicted for the same crime in the same state provides an upper bound on the *ratio* of wrongful conviction rates across races among these defendants. Our estimates of this statistic reveal that among those sentenced to incarceration for rape in the United States between 1983 and 1997, the wrongful conviction rate among white defendants was less than two-thirds of what it was for black defendants. Our results with respect to murder are inconclusive.

Keywords: Wrongful convictions; Racial Bias; Judicial Bias; Exonerations; DNA Evidence (JEL K14, J15)

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I - Introduction

A widely agreed upon principle of a just criminal justice system is that it does not systematically treat individuals differentially based on personal characteristics such as race. This in turn has lead researchers to consider whether particular justice systems, such as that of the United States, are racially biased. To date, these studies have focused primarily on evaluating racial bias with respect *policing* and *sentencing*, but there have been few attempts to empirically evaluate whether the justice system in the United States leads to racially biased outcomes with respect to *wrongful* convictions.

While the presence of systematic policing and sentencing disparities across different racial groups is certainly a cause for concern, the costs of wrongful convictions and differential rates of wrongful convictions across racial groups are arguably just as high. Executing, incarcerating, or imposing other forms of serious punishments on innocent individuals obviously imposes severe and unjust costs on those wrongfully convicted and those who are close to them. Moreover, to the extent to which rates of wrongful convictions differ substantially across racial groups may lead to distrust or outright rejection of the justice system as a whole by substantial parts of society.

The interest of this paper is to attempt to empirically evaluate whether wrongful conviction rates differ across races, at least among those convicted for rape and murder. On the face of it, this seems like a very difficult task as it is simply not possible to know innocence or guilt with certainty for a large fraction of those convicted. However, there does exist one set of convicts for which we know innocence with near certainty---namely those who are exonerated due to DNA evidence of innocence.

Given this, the first part of this paper attempts to determine what can potentially be learned about wrongful conviction rates from DNA exonerations. Based on the information we have about the DNA exoneration process, we argue that a reasonable starting point is to assume that conditional on innocence, type of crime, state of conviction, and plea status, the likelihood that exculpatory DNA evidence exists and is accepted by a court is independent of defendant race and strength of initial evidence (at least for rape cases and murder cases which constitute the two types of cases mostly likely to have DNA exonerations). As we show below, if this is the case, then the expected value of the ratio of *DNA exoneration rates* across races among individuals convicted for the same crime in the same state provides a weak upper bound on the ratio of *wrongful conviction rates* across races for that crime in that state. The importance of this is that while wrongful conviction rates by race cannot be observed, exoneration rates by race can be. Thus, data on exoneration rates by race can potentially uncover information about the ratio of wrongful conviction rates across races.

The second part of this paper then attempts to apply the lessons learned from the first part of the paper to data in order to estimate whether there exists racial bias with respect to wrongful convictions for rape and murder. If one is willing to accept the assumption that conditional on innocence, type of crime, state of conviction, and plea status, the likelihood that exculpatory DNA evidence exists and is accepted by a court is essentially independent of defendant race and strength of evidence, then our results are quite dramatic when it comes to rape. In particular, our findings suggest that for those convicted between 1983 and 1997, the *rate of wrongful convictions among white defendants convicted for rape is less than two-thirds the rate of wrongful convictions among black defendants convicted for rape*. Or, to put another way, black defendants convicted for rape are over one and a half times more likely to be innocent than white defendants convicted for rape. We show that these findings strongly reject the null hypothesis that the wrongful conviction rate is equal across races among those convicted for rape, and these results are robust to using all exonerations rather than just DNA exonerations, over different subsamples of conviction cohorts, and across the majority of states.

Notably however, while our results suggest a relatively large racial discrepancy in wrongful conviction rates for rape, our results with respect to murder are inconclusive. Note, this does not necessarily mean that the wrongful conviction rate for murder is equal across races, it just means that our procedure provides no evidence that it is not. However, we do think it is plausible that racial differences in wrongful conviction rates are more pronounced with respect to rape than murder, as it appears that one of the factors that contributes to a large fraction of wrongful rape convictions but not murder convictions is mistaken eyewitness identification of the perpetrator, and there is evidence that this phenomenon may be more likely when the perpetrator is black.

As alluded to above, our results are derived under the assumption that the DNA exoneration process is racially neutral (at least among those innocent defendants convicted for the same crime, in the same state, with the same plea status). While we argue that this seems like a reasonable assumption given what we know about the DNA exoneration process, we have little direct evidence regarding this matter. However, for one to believe that our results with respect to rape are actually being driven by a racial bias toward black defendants in the DNA exoneration process, for example due to wrongful conviction advocates being more likely to take up DNA appeals for black defendants than white defendants, not only would this bias have to be quite substantial, but it would also have to arise only with respect to rape cases *but not murder cases*. There is little evidence for this and it is hard to see why this would be true.

II - Background on Wrongful Convictions, Race, and Exonerations

There have been a substantial number of writings looking at the issue of wrongful convictions going back all the way to at least Borchard (1932). A recent summary of this work appears in Ramsey and Frank (2007). As they describe, much of the published work on wrongful convictions have been case studies of particular wrongfully convicted individuals who were exonerated (e.g., Barlow 1999; Cooper, Cooper, and Reese 1995; Frisbie and Garnett 1998; Hirsch 2000; Humes 1999; Linscott and Frame 1994;

Potter and Bost 1997; Protess and Warden 1998). However, others have tried to provide a broader picture by looking at a collection of exonerated cases (Brandon and Davies 1973; Christianson 2004; Huff and Rattner 1988).

How Often Do Wrongful Convictions Occur?

The cases contained in the cited works above encompass only a fraction of the wrongful convictions that have been uncovered to date, but make it clear that wrongful convictions are not just exceedingly rare anomalies, but rather numerous enough to truly affect society's perceptions of the justice system. Indeed, the National Registry of Exonerations has documented over 1,600 exonerations in the past 25 years, which clearly undercounts the true number of individuals wrongfully convicted over this time period, as for many wrongfully convicted individuals exculpatory evidence and/or hearings for such evidence never arise.

Clearly, trying to uncover the actual rate of wrongful convictions is exceedingly difficult because in many cases the actual guilt of the convicted individual is known only by that individual with certainty (Gross and O'Brien 2008). However, a variety of scholars have tried to uncover the underlying rate of wrongful convictions via a variety of methods. For example, Huff, Rattner, and Sagarin (1986), and later Ramsey and Frank (2007), surveyed judges, prosecutors, public defenders and police officials about their opinions regarding the frequency of wrongful convictions. Not surprisingly, the results of these surveys showed substantial variance in individuals' perceptions of the likelihood of wrongful felony convictions, ranging from "never" to "more than 10%." It is also by no means clear how accurate even these "more informed" individuals are in their perceptions are regarding the frequency of wrongful convictions.

A few studies have tried more data driven approaches. Spencer (2007) compares jury verdicts to judges' perceptions of guilt at the same trial. Under some statistical assumptions, his results suggest the rate of wrongful convictions by juries could be on the order of 8 to 10 percent. Risinger (2007) estimates the rate of wrongful convictions in capital rape-murder cases by dividing the number of DNA exonerations among capital rape-murder convictions that occurred between 1982 and 1989 by the number of capital rape-murder convictions over the same time period, which gives a wrongful conviction rate in such cases of at least 2.2 percent. As he explains however, this clearly understates the true rate, as DNA evidence is not available in all cases. Using a conservative measure that useable DNA samples existed in only 67 percent of rape-murder cases, the wrongful conviction rate rises to being at least 3.3 percent.

More recently, Gross et al. (2014) also make use of data on exonerations in capital murder cases to estimate an arguably conservative measure of the wrongful conviction rate for such cases. Under some assumptions regarding how the likelihood of an exoneration given innocence is affected by the threat of being on death row, but most death row defendants are removed from death row over time, they use a survival analysis model to predict what the rate of exonerations would be if all death row inmates remained under such sentences indefinitely. Their estimates suggest the wrongful conviction rate in capital murder cases since 1973 must be at least 4.1 percent.

Why Do Wrongful Convictions Occur?

The ways in which wrongful convictions occur can be grouped into a couple of distinct categories. First, the evidence that arises against a defendant may actually be false, for example police and/or prosecutors may plant or misrepresent evidence (Boyer 2001; Joy 2006), confessions may be coerced (Kassin 1997; Leo and Ofshe 1998), informants may be lying (Zimmerman 2001), or eyewitnesses may make mistakes (Huff et al. 1996; Scheck et al. 2000). Second, the evidence that arises against a defendant might be true, but such evidence provides only imperfect information regarding defendant guilt. Hence, there may be cases where judges and/or juries view the (true) evidence against a given defendant to be sufficient to show guilt "beyond a reasonable doubt," even though the defendant is actually innocent.[1] All of these issues may then be exacerbated for a variety of reasons (Huff 2002; Huff, Rattner, and Sagarin 1986; Castelle and Loftus 2001), including ineffective counsel (Radelet, Bedau, and Putnam 1992) and political and societal pressures. For example, the wrongful convictions in the Central Park Five case, where five young black men were falsely convicted of raping a young woman jogging in New York City's Central Park, highlight how political pressure can lead to and/or exacerbate many the issues mentioned above (Smith 2002).

Race and Wrongful Convictions

Given the discussion above, wrongful convictions may be more likely to arise with respect to members of one race than another for several reasons. First, the court process may be racially biased regarding the likelihood of conviction at trial. For example, judges and/or juries could be less averse to convicting innocent defendants of one race than another, or judges and/or juries are similarly averse to convicting innocent defendants of all races, but hold stronger prior beliefs of guilt regarding defendants of one race relative to another. In both of the above cases, juries and/or judges would then require less evidence to meet the "beyond a reasonable doubt" standard for guilt for defendants of one race relative to another.

[1] Papers such as Grossman and Katz (1983), Reinganum (1988), Miceli (1990), Friedman and Wickelgren (2006), and Bjerk (2008) consider theoretically how courts may try to minimize punishment of the innocent when information on defendant guilt is uncertain. Relatedly, Curry and Klumpp (2009), develop a game theoretic model of statistical discrimination showing how imperfect information regarding defendant guilt can lead to differential rates of wrongful conviction by income or racial groups.

Second, even if the court process is racially unbiased, a higher fraction of defendants of one race may be wrongfully convicted than defendants of another race if the likelihood of being falsely charged differs across races. This could be due to police or prosecutors employing a lower standard of evidence for determining when to charge individuals of one race relative to another (for example due to the reasons discussed in the previous paragraph), a greater likelihood of police or prosecutors to plant or distort evidence against individuals of one race relative to another, or because informants are more likely to lie or witnesses are more likely to be mistaken when defendants are of one race relative to another.

Third, and finally, the wrongful conviction rate can differ across races because wrongfully charged defendants of one race are more likely to be induced to accept a plea bargain than those of another race.

All of the reasons above seem arguably possible, but direct evidence for most is at best anecdotal. However, as we will return to later in the paper, eyewitness error, where an eyewitness to the crime (often the victim in rape cases) identifies an innocent individual as the perpetrator with high confidence, may be a particular issue when it comes to race and wrongful conviction. Indeed, because of concerns about eyewitness identification error, the National Academy of Sciences recently delivered a wide-ranging report on the issue (National Research Council 2014). Eyewitness error can be exacerbated by positive reinforcement from police (Wells and Bradfield 1988, 1989), and also, most relevant to this study, may be more prevalent when the eyewitness is white and the perpetrator is black, particularly in rape cases (see Meissner and Brigham (2001) for a thorough review of this literature).

While a variety of studies have looked at issues regarding racial bias in the charging and sentencing process (e.g., Bushway and Piehl 2001; Mustard 2001; Everett and Wojtkiewicz 2002; Shermer and Johnson 2010; Ulmer, Light, and Kramer 2011; US Sentencing Commission 2012; Abrams, Bertrand, and Mullainathan 2012; Raphael and Stoll 2013; Rehavi and Starr 2014) and in policing (e.g., Knowles, Persico, and Todd 2001; Grogger and Ridgeway 2006; Ridgeway 2006; Anwar and Fang 2006; Gelman, Fagan, and Kiss 2007; Antonovics and Knight 2009; Donohue and Levitt 2001),[2] there are only a handful of studies that attempt to provide evidence related to racial inequities in the rate of wrongful convictions.

To date, most studies on racial disparities in wrongful convictions have either focused on case studies (Parker et al 2001), or simply looked at the racial composition of a collection of exonerated defendants (Bedau and Radelet 1987; Huff et al. 1996; Radelet et al. 1996; Gross and O'Brien 2008). Harmon (2001) extends this type of analysis by comparing case and defendant characteristics for cases

[2] Relatedly, Alexander (2010) provides a very compelling and insightful critique regarding how the criminal justice system was used throughout the 20th century to disproportionately target black Americans, particularly in the era of desegregation.

that were exonerated relative to “matched” cases that were not. In general, these studies show that a relatively high fraction of those who have been exonerated are black at least relative to population demographics.

Harmon (2004) and Alesina and La Ferrara (2014) extend this line of inquiry in a new way by focusing on capital murder convictions only, and consider how the eventual fate of the defendant depends on the combination of the defendant and the race of the victim. In particular, Alesina and La Ferrara (2014) argue that while the likelihood that a conviction is overturned on statutory appeal may differ by race of the victim (possibly due to differences in circumstances of the crime that correlate with race of victim), any such difference should not differ by race of the defendant. However, they find that the likelihood that the conviction is overturned on statutory appeal for non-white defendants is significantly higher when the victim is white than when the victim is non-white, but this is not true for white defendants (if anything it is just the opposite). They argue that this provides evidence of racial bias with respect to the imposition of the death penalty.

Our analysis below is complementary to Alesina and La Ferrara’s (2014) approach and findings, but differs in several important ways. First, while Alesina and La Ferrara’s (2014) approach is confined to death penalty convictions, we look at racial differences in wrongful conviction rates over all murder convictions as well as all rape convictions. Second, while under certain assumptions Alesina and La Ferrara’s (2014) approach can test for whether black defendants sentenced to death are more likely to be wrongfully convicted than white defendants sentenced to death, it is limited in quantifying just how large this bias is. For example, it cannot very precisely answer the question “how much higher is the rate of wrongful conviction among black defendants sentenced to death relative to white defendants sentenced to death?” Third, and arguably most importantly, while one interpretation of Alesina and La Ferrara’s (2014) results are that black defendants convicted for murdering a white victim are more likely to be innocent than white defendants convicted for murdering a white victim, another interpretation is that black defendants wrongfully convicted for murdering a white victim are more likely to be given the death penalty than white defendants wrongfully convicted for murdering a white victim. As Alesina and La Ferrara (2014) discuss, their procedure cannot distinguish between these two possibilities since they only look at defendants who were given the death penalty.[3] We think our approach is the first to specifically and precisely test for differences in the relative frequency of *wrongful conviction* across races.

Another important study that provides a background and motivation for our work that follows is Anwar, Bayer, and Hjalmarsson (2012). They find that black defendants are significantly more likely to be convicted when juries are formed from an all-white jury pool than when there is even a single black

[3] Moreover, Alesina and La Ferrera’s (2014) results could also be due to racial differences in judicial error rates in capital murder cases rather than racial differences in wrongful conviction rates per se.

member of the jury pool. While again these results do not necessarily mean that black defendants are more likely to be *wrongfully* convicted than white defendants, these results do suggest that the evidence required for conviction may be quite sensitive to the interaction between the race of the defendant and the racial composition of the jurors.

Exonerations, DNA Evidence, and Race

There are a variety of ways wrongfully convicted defendants later become exonerated. Sometimes exonerations arise due to witnesses recanting or because witnesses were later found to have perjured themselves, because prosecutors or police were found to have manufactured or withheld crucial evidence, or because it was determined that the defendant had inadequate defense. However, all of these types of exonerations are generally quite difficult to achieve, as not only must the defendant and his lawyers show that such issues occurred, but also must then argue that their revelation must imply that the convicted defendant is actually not guilty.

Another avenue to exoneration has been through DNA evidence. The first time such evidence was used to help exonerate a convicted felon in the United States was 1989.[4] One of the most important contributions of DNA evidence is that the cost of performing the test is quite low ($500 - $1500), at least relative to the time cost for lawyers, but the evidentiary value can be extremely high (Scheck and Neufeld 2001). However, it is clear that in many crimes exclusionary DNA evidence simply would not exist. Even in cases where DNA material is likely to be present at the crime scene and potentially exculpatory to the defendant, most notably in rape cases, testable samples still often do not exist. As stated by Barry Scheck and Peter Neufeld, the co-founders of the Innocence Project (the leading organization in securing post-conviction DNA exonerations), "(t)he practical roadblock faced by inmates seeking to prove their innocence (via DNA evidence) is finding the evidence. In 75 percent of the Innocence Project cases, matters in which it has been established that a favorable DNA result would be sufficient to vacate the inmate's conviction, the relevant biological evidence has either been destroyed or lost" (Scheck and Neufeld 2001, pp. 245).

The vast majority of innocent defendants who are exonerated via DNA evidence get help from groups such as the various national and state level Innocence Projects and law clinics run out of law schools. How these entities choose which cases to pursue generally starts with a letter from a convicted defendant (or his family) maintaining innocence. Based on these letters and possibly follow-up questionnaires, a determination is made regarding whether the case merits further investigation. This

[4] States begin to create DNA databases of convicted offenders going back to 1988 (see Doleac 2016). However, these databases are primarily used to tie known offenders to new cases, but are less useful for exonerating innocent defendants of crimes they did not commit.

determination almost always hinges on whether DNA evidence could potentially be exculpatory if it exists. For example, the national Innocence Project says that it will only consider cases where

> "There is physical evidence that, if subjected to DNA testing, will prove that the defendant is actually innocent. This means that physical evidence was collected – for example blood, bodily fluids, clothing, hair – and if that evidence can be found and tested, the test will prove that the defendant could not have committed the crime. Examples of crimes where biological evidence can prove innocence include sexual assaults, homicides, assaults with close physical contact or a struggle and some robberies—where physical evidence was collected that was worn by or in contact with the actual perpetrator." (http://www.innocenceproject.org/submit-case)

According to Justin Brooks, Director of the California Innocence Project, and Carmichael and Caspers (2015), such criteria also holds true for the California Innocence Project and the several different legal aid projects in Texas created to uncover wrongful convictions.[5] Based on these initial reviews, cases determined to merit further investigation are then assigned to investigators as they become available.

Given the information we have seen, we think a natural starting point for our analysis below is to consider a model where conditional type of crime, state of conviction, and plea status, whether or not an innocent defendant is exonerated by DNA evidence is the realization of a random variable that is independent of the defendant's race and the strength of the evidence against the defendant that led to the initial conviction.

We feel that it is relatively uncontroversial to assume that the likelihood exculpatory DNA evidence *exists* is independent of initial evidence against the defendant (especially after conditioning on crime type, state of conviction, and plea status). Specifically, there doesn't seem to be any obvious link between the existence of planted evidence, mistaken witness identification, lying informants, or even a strong circumstantial evidence against the defendant, and whether DNA evidence existed and was collected at the crime scene. With respect to defendant race and the *existence* of DNA evidence, again it seems unlikely that there could be a strong connection. While it is possible that some police officers would be less inclined to collect DNA evidence or more inclined to destroy or otherwise invalidate DNA samples if they knew the defendant was of one race versus another, this seems unlikely to be widespread enough to matter both because perpetrator race is often unknown at the time of evidence collection, as well as the fact that even racially biased police officers may still want to collect such evidence in all cases in case it could be used to help secure a conviction. Moreover, many of the defendants in the sample we examine were convicted prior to DNA testing. Hence, for them, the existence of DNA evidence simply depends on what evidence was collected and retained over the years.

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[5] The national Innocence Project currently only considers cases occurring in states other than Arizona, California, Illinois, Michigan, Ohio, Washington, and Wisconsin. However, all of these states have other

However, it is perhaps less obvious whether, after conditioning on type of crime type, state of conviction, and plea status, the likelihood that existing exculpatory DNA evidence is *tested and heard* by a court is unrelated to defendant race or the evidence against the defendant. On the one hand, it is certainly plausible that groups such as the Innocence Project that work to free innocent defendants primarily via DNA testing are more prone to take on cases where the defendant is of one race than another, or cases where a particular type of evidence was key to conviction relative to another. On the other hand, race of the defendant and much of the evidence against a defendant would often not be even known to advocacy groups such as the Innocence Project until after the case was already selected for further investigation.

When we discussed these issues with Justin Brooks, Director of the California Innocence Project, he said "(t)here is no reason for me not to believe the likelihood of exoneration for innocent whites is the same as it is for innocent blacks. Our process of case review is color blind and habeas is as well. There are no juries involved and it is mostly a paper process. There is no reason to believe black defendants have an advantage." Moreover, he concurred that in DNA exoneration cases the primary constraint is whether there exists testable DNA material that would be exculpatory, which seems unlikely to be correlated with race of defendant or with the strength of the other evidence against the defendant.

In general, as stated above, given the information we have we think it natural to at least consider the implications of a model where the DNA exoneration process is the same for all innocent defendants in the same state with the same plea status regardless of their race or initial evidence against them.

III –Uncovering Racial Differences in Wrongful Convictions Rates from DNA Exoneration Rates

We are interested in estimating how *the wrongful conviction rate* for a particular crime (e.g., rape) differs across races in the United States, where the *wrongful conviction rate* refers to the fraction of defendants convicted for a given crime who are actually innocent of that crime. In terms of the notation to be used below, if we let π_A and $\pi_{B,}$ be the respective fractions of defendants from race A and race B convicted for a given crime who are actually innocent, then we want to understand the extent to which π_A differs from π_B among a broad set of convicted defendants in the United States. The obvious hurdle is that π_A and $\pi_{B,}$ cannot be directly observed. However, suppose we can observe the fraction of defendants of each race *r* convicted in each state *s* for any given crime who have been exonerated by DNA evidence (denoted $EXONRT_{r,s}$). The question of interest is under what conditions can such information be used to recover information about the relative difference between π_A and π_B?

III(a) – Modelling the Relationship Between Wrongful Conviction Rate and DNA Exoneration Rate

As discussed previously, within a given state, the wrongful conviction rate for a given crime can differ across races for several different reasons. We can capture these reasons mathematically via the following equation:

$$\pi_{r,s} = \frac{I_{r,s}\left(P_{r,s} + (1 - P_{r.s})T_{r,s}\right)}{C_{r,s}} \quad (1)$$

where $\pi_{t,s}$ is the wrongful conviction rate among defendants from race *r* in state *s*, $I_{r,s}$ is the number of innocent defendants from race *r* in state *s* who are mistakenly and falsely charged, $P_{r,s}$ is the fraction of mistakenly and falsely charged defendants from race *r* in state *s* that are induced to plead guilty, $T_{r,s}$ is the trial conviction rate among the mistakenly and falsely charged defendants of race *r* in state *s* who go to trail, and $C_{r,s}$ is the total number of convicted individuals from race *r* in state *s* (all this discussion assumes we are focusing within one particular type of crime).

Equation (1) captures the primary ways in which the wrongful conviction rate can differ across races within a given state as discussed previously. Namely, the number of mistakenly or falsely charged defendants relative to convictions ($I_{r,s}/C_{r,s}$) can differ across races, the fraction of mistakenly or falsely charged defendants who are induced to plead guilty ($P_{r,s}$) can differ across races, or the likelihood of conviction at trial among mistakenly or falsely charged defendants ($T_{r,s}$) may differ across races.

Clearly, directly observing the wrongful conviction rate, or any of the key parameters determining the wrongful conviction rate discussed above, is generally not possible. However, let us now consider the relationship between wrongful convictions and exonerations based on DNA evidence. We will take it as a given that one must be innocent of the crime of conviction to be exonerated of this crime based on DNA evidence. However, not all wrongfully convicted defendants are exonerated due to DNA evidence. As discussed above, to be exonerated by DNA evidence, there must have been DNA evidence at the crime scene, this evidence must have been collected and saved properly, this evidence must be exculpatory in the sense that it excludes the possibility that the wrongfully convicted defendant committed the crime, and such evidence must be heard and accepted by the court.

Due to differences in state laws and procedures with respect to handling DNA evidence and allowing hearings regarding DNA evidence for convicted defendants, the likelihood of a DNA exoneration may differ for wrongfully convicted defendants convicted in different states. Moreover, courts (in some states) are less likely to grant post-conviction hearings if the defendant pled guilty than if he was found guilty at trial. So, even within a state, wrongfully convicted defendants who pled guilty may face a lower likelihood of a DNA exoneration than the wrongfully convicted who were convicted at trial.

However, given our discussion at the end of the previous section, we think it reasonable to derive the implications of a model where, conditional on state of conviction and plea status, whether or not exculpatory DNA evidence exists and is tested and heard by a court for *any* given innocent defendant is the realization of an independent random variable drawn from the *same* distribution. Given this, the expected DNA exoneration rate among defendants of race *r* in state *s* can be captured by the following equation

$$(2) \qquad E[EXONRT_{r,s}] = \frac{I_{r,s}\left(\rho_s^P P_{r,s} + \rho_s^T (1 - P_{r.s})T_{r,s}\right)}{C_{r,s}}$$

where ρ_s^P is the (Bernoulli) likelihood that there exists exculpatory DNA evidence that is tested and presented before a court for innocent defendants who *plead guilty* in state *s*, and ρ_s^T is the (Bernoulli) likelihood that there exists exculpatory DNA evidence that is tested and presented before a court for innocent defendants *convicted at trial* in state *s* (again, for a given particular crime). The rest of the notation follows from equation (1). We think it is reasonable to assume that $\rho_s^P \leq \rho_s^T$, or that among innocent defendants, the likelihood that there exists exculpatory DNA evidence that is tested and presented before a court is at least as high among the wrongfully convicted who pled innocent but were convicted at trial as among the wrongfully convicted who pled guilty to the crime. Note that ρ_s^P and ρ_s^T do not have race *r* subscripts, again emphasizing the assumption that conditional on defendant plea status and conviction state, the likelihood of a DNA exoneration is independent of defendant race.

Given equations (1) and (2), we can now state the following key proposition

Proposition - If exoneration by DNA evidence for all innocent defendants convicted for the same crime in the same state with the same plea status is the realization of an independent random variable drawn from the same distribution, then in expectation, the ratio of DNA exoneration rates across races among defendants convicted for the same crime in the same state provides an upper bound on the ratio wrongful conviction rates across races among these defendants.

Mathematically, given two races A and B in state *s*, the above proposition can be summarized as

$$E\left[\frac{EXONRT_{A,s}}{EXONRT_{B,s}}\right] \geq \frac{\pi_{A,s}}{\pi_{B,s}}$$

To prove the above proposition, first note that $E\left[\frac{EXONRT_{A,s}}{EXONRT_{B,s}}\right] = E\left[\frac{EXON_{A,s}}{EXON_{B,s}} \times \frac{C_{B,s}}{C_{A,s}}\right]$, where $EXON_{r,s}$ is the number of DNA exonerated defendants from race *r* in state *s* and $C_{r,s}$ again refers to the number of convicted individuals of race *r* in state *s*. Because convictions necessarily take place before the random process that determines DNA exonerations, the ratio of convictions in above expression is simply a constant with respect to the expectation, meaning

$$E\left[\frac{EXONRT_{A,s}}{EXONRT_{B,s}}\right] = E\left[\frac{EXON_{A,s}}{EXON_{B,s}}\right] \times \frac{C_{B,s}}{C_{A,s}}$$

Moreover, if after conditioning on plea status, conviction state, and crime, the likelihood of a DNA exoneration for each innocent defendant is an i.i.d. random variable, then the total number of defendants of race *r* in a particular state exonerated by DNA evidence would also be an independent random variable. Therefore, among defendants convicted in the same state for the same crime, the expected value of the ratio of exoneration rates across races is simply the expected value of the ratio of two independent variables times a constant. Further, given any two independent random variables X and Y, it will be true that E[X/Y] = E[X]E[1/Y], which will mean Jensen's inequality implies E[X/Y] ≥ E[X]/E[Y]. Therefore, via Jensen's inequality we also know

$$E\left[\frac{EXONRT_{A,s}}{EXONRT_{B,s}}\right] = E\left[\frac{EXON_{A,s}}{EXON_{B,s}}\right] \times \frac{C_{B,s}}{C_{A,s}} \geq \frac{E\left[EXON_{A,s}\right]}{E\left[EXON_{B,s}\right]} \times \frac{C_{B,s}}{C_{A,s}} = \frac{E\left[EXONRT_{A,s}\right]}{E\left[EXONRT_{B,s}\right]}$$

This means that to prove the proposition above, we must simply show

$$\frac{E\left[EXONRT_{A,s}\right]}{E\left[EXONRT_{B,s}\right]} \geq \frac{\pi_{A,s}}{\pi_{B,s}}$$

Using equations (1) and (2), the above equation is equivalent to

$$\frac{\frac{I_{A,s}}{C_{A,s}}\left(\rho_s^P P_{A,s} + \rho_s^T (1 - P_{A.s}) T_{A,s}\right)}{\frac{I_{B,s}}{C_{B,s}}\left(\rho_s^P P_{B,s} + \rho_s^T (1 - P_{B.s}) T_{B,s}\right)} \geq \frac{\frac{I_{A,s}}{C_{A,s}}\left(P_{A,s} + (1 - P_{A.s}) T_{A,s}\right)}{\frac{I_{B,s}}{C_{B,s}}\left(P_{B,s} + (1 - P_{B.s}) T_{B,s}\right)}$$

Simplifying and re-writing the above equation we get

$$\begin{aligned}&\left(P_{B,s} + (1 - P_{B.s}) T_{B,s}\right)\left(\rho_s^P P_{A,s} + \rho_s^T (1 - P_{A.s}) T_{A,s}\right) \\ &\qquad \geq \left(P_{A,s} + (1 - P_{A.s}) T_{A,s}\right)\left(\rho_s^P P_{B,s} + \rho_s^T (1 - P_{B.s}) T_{B,s}\right)\end{aligned}$$

Further simplifying and re-writing gives

$$\rho_s^T P_{B,s}(1 - P_{A.s})T_{A,s} + \rho_{t,s}^P P_{A,s}(1 - P_{B.s})T_{B,s} \geq \rho_s^T P_{A,s}(1 - P_{B.s})T_{B,s} + \rho_s^P P_{B,s}(1 - P_{A.s})T_{A,s}$$

Re-writing once more gives

$$\rho_s^T\left[P_{B,s}(1 - P_{A.s})T_{A,s} - P_{A,s}(1 - P_{B.s})T_{B,s}\right] \geq \rho_s^P\left[P_{B,s}(1 - P_{A.s})T_{A,s} - P_{A,s}(1 - P_{B.s})T_{B,s}\right]$$

Cancelling the identical terms in brackets on each side of the equation, the above equation reduces to $\rho_s^T \geq \rho_s^P$, which was assumed to be true in the statement of the proposition, thus the proposition is proved.

The above proposition shows that, in expectation, the ratio of DNA exoneration rates across races in a particular state for a particular crime provides a weak upper bound on the ratio of wrongful conviction rates across races in that state for that crime.

To calculate the relative rate of wrongful convictions across races over the United States as a whole, we can take the weighted mean of the ratios of wrongful conviction rates across states, or

$$\frac{\pi_A}{\pi_B} = \sum_{s=1}^{S} \omega_s \frac{\pi_{A,s}}{\pi_{B,s}}$$

where S is the number of states and the weights ω_s correspond to the fraction of all convicted defendants who are convicted in state *s* (for the particular crime of interest). Given the earlier proposition, it is straightforward to then see that

$$\frac{\pi_A}{\pi_B} \leq \sum_{s=1}^{S} \omega_s E\left[\frac{EXONRT_{A,s}}{EXONRT_{B,s}}\right]$$

Finally, given the assumption that the likelihood of a wrongfully convicted defendant is exonerated by DNA evidence is an i.i.d. random variable conditional on state and plea status, the ratio of exoneration rates will be independent across states, meaning above expression will in turn imply

(3) $$E\left[\sum_{s=1}^{S} \omega_s \frac{EXONRT_{A,s}}{EXONRT_{B,s}}\right] \geq \frac{\pi_A}{\pi_B}$$

or that, in expectation, the weighted mean of the ratio of DNA exoneration rates across races by state will provide an upper bound on the ratio of wrongful conviction rates across races in the United States. This will be the basis for our empirical estimation strategy which we discuss in more detail below.

In summary, by using observable data regarding DNA exonerations and convictions by race and state of conviction for a given crime, we can potentially obtain information regarding an otherwise unobservable parameter of interest.

IV - Data

Data for this analysis comes from two sources. First, the data on exonerations comes from the National Registry of Exonerations. This registry was co-founded by Samuel Gross (Professor of Law at the University of Michigan Law School) and Rob Warden (Executive Director emeritus and co-founder of the Center for Wrongful Convictions at Northwestern University School of Law), and is a project facilitated through the University of Michigan Law School. The Registry has collected information about all known exonerations in the United States from 1989 to the present. It relies entirely on publicly available data.

Technically, as stated by the website, for a case to be included in this registry it must "involve an individual who was convicted for a crime and later was either: (1) declared to be factually innocent by a government official or agency with the authority to make that declaration; or (2) relieved of all the consequences of the criminal conviction by a government official or body with the authority to take that action. The official action may be: (i) a complete pardon by a governor or other competent authority, whether or not the pardon is designated as based on innocence; (ii) an acquittal of all charges factually related to the crime for which the person was originally convicted; or (iii) a dismissal of all charges related to the crime for which the person was originally convicted, by a court or by a prosecutor with the authority to enter that dismissal. The pardon, acquittal, or dismissal must have been the result, at least in part, of evidence of innocence that either (i) was not presented at the trial at which the person was convicted; or (ii) if the person pled guilty, was not known to the defendant, the defense attorney and the court at the time the plea was entered. The evidence of innocence need not be an explicit basis for the official action that exonerated the person." In other words, cases where a conviction is vacated simply due to legal errors are not included as exonerations in this data.

The Registry of Exonerations has documented well over 1,300 exonerations since 1989. For each exoneration the data set includes a variety of information including the exonoree's name, age at conviction, race, state where conviction occurred, conviction crime, sentence, year convicted, year exonerated, and whether DNA evidence played a key role in the exoneration. As discussed above, for the purposes of this paper we are primarily interested in DNA exonerations, which we define as being cases in which a person who has been convicted of a crime but is later has this conviction pardoned, acquitted, or dismissed based on DNA evidence of *innocence*.

The Registry of Exonerations reveals that there have been 425 known DNA exonerations since 1989. Of particular note for this paper, 182 of these DNA exonerations related to murder convictions, 196 related to rape convictions, and only 47 were for any other type of crime. Relatedly, the fraction of exonerations that are due to DNA evidence differs quite dramatically across crime type. While 69 percent of rape exonerations are based on DNA evidence, only 22 percent of murder exonerations are based on DNA evidence, and only 7 percent of exonerations for other types of crime are based on DNA evidence.

Figure 1a shows the time path of DNA exonerations over time overall, as well as for murder and rape cases separately. The first DNA exoneration occurred in 1989 and then climbed relatively quickly thereafter. Figure 1b looks at DNA exonerations a bit differently, tracking DNA exonerations by conviction year cohort. As can be seen, very few defendants convicted prior to 1975 have been exonerated by DNA. This is mostly likely due to the fact that DNA exoneration technology was not available until the late 1980s. The vast majority of DNA convictions have been among defendants convicted between 1980 and 2000. The reasons for the relative dearth of DNA exonerations among those convicted post 2000 are likely twofold. First, DNA exonerations take time. Overall, among those exonerated by DNA evidence, the average time between conviction and exoneration was almost 16 years. Clearly those convicted before 1989 could not be exonerated by DNA evidence right away. However, even among those exonerated by DNA convicted after 1989, the average time to exoneration was almost 12 years. Second, it is likely that testing DNA of evidence prior to conviction has become far more frequent over time, making wrongful convictions (at least among those with testable DNA evidence) less frequent.

In addition to exonerations by race, crime type, and state, to compute our test statistics we also need convictions by race, crime type, and state. It turns out this data is harder to find than one might think. Data on convictions by crime type are collected National Judicial Reporting Program. These data come from a sample design that can be weighted to be nationally representative. However, these data will not be representative at the state level. Moreover, these data are only collected every other year and the series only goes back to 1988. This is problematic as Figure 1b shows that a large fraction of exonorees were convicted in the early to mid-1980s. Furthermore, defendant race is missing for a large fraction of this data.

Because of these issues, the second data source we end up using is the National Corrections Reporting Program (NCRP). This data set is housed at Inter-university Consortium for Political and Social Research (ICPSR) and collected by the Bureau of Justice Statistics in the United States Department of Justice. This data set provides offender-level data on admissions to state prisons. Since all of the exonerated defendants in our exoneration data that were convicted for rape or murder were sentenced to prison, defendants who are sentenced to prison for rape or murder is arguably the correct population for our analysis. Moreover, the NCRP data is helpful in that the series is collected annually going all the way back to 1983, has race data for most defendants (over 95 percent of murder and rape defendants), and is meant to be inclusive of all admissions in each state. However, this data set also has some limitations. First, Hispanic ethnicity is missing for many defendants, and even when reported, the documentation for these data suggest that there may be considerable reporting error with respect to Hispanic ethnicity. Therefore, we will only evaluate wrongful conviction rates across "black" and "white" defendants, where both racial categories are inclusive of Hispanic ethnicity. Maybe more notably, as highlighted by Neal and Rick (2016), the NCRP data only includes data from states, and even prisons within states, that voluntarily submit this data, meaning not all states report data every year, and not all prison admissions are reported for a given state in a given year. We discuss in the next section how we deal with this issue.

We also employ the NCRP data only for those convicted and admitted to prison between 1983 and 1997. The reason we limit our analysis to defendants admitted in these years is that, as discussed above, it takes substantial time for DNA exonerations to move through the system. Therefore, when computing exoneration rates, we need this rate to be among defendants who have had ample time for their DNA evidence to come to light, be tested, and be presented in court. As alluded to above, the mean time to DNA exoneration for those in the exoneration sample is 16 years. It is also true though, that for defendants convicted prior to 1989, DNA exoneration is simply not possible until well after conviction due to the fact that DNA technology was not available until the later 1980s, meaning some of the lag between conviction and exoneration is due to this technological constraint. However, even if we just look at defendants convicted between 1989 and 1995, among those exonerated by DNA, the median time was 11 years with the 90^{th} percentile being 19 years. Hence, by limiting our analysis to those convicted prior to 1998 we feel relatively confident that the vast majority of DNA exonerations that will occur with respect to these cohorts have already happened.

V –Using Exoneration Rates to Estimate Relative Rates of Wrongful Conviction Across Races

As discussed above in Section III, in expectation, the weighted mean across states of the ratio of the DNA exoneration rate for defendants of race A relative to defendants of race B will provide an upper bound on the ratio of the wrongful conviction rates among defendants of race A relative to defendants of race B across the United States (see equation (3) above). This relationship motivates our test statistic.

Specifically, to determine whether the wrongful conviction rate among convicted individuals of race A is less than the wrongful conviction rate among convicted individuals of race B, our goal is to test whether $\theta_{A,B} < 1$, where

$$\theta_{A,B} = E\left[\sum_{s=1}^{S} \omega_s \frac{EXONRT_{A,s}}{EXONRT_{B,s}}\right]$$

or equivalently

$$\theta_{A,B} = E\left[\sum_{s=1}^{S} \omega_s \frac{EXON_{A,s}/C_{A,s}}{EXON_{B,s}/C_{B,s}}\right]$$

where $EXON_{r,s}$, and $C_{r,s}$ are respectively the number of DNA exonerations and number of convictions of defendants of race r in state s for the crime of interest, and the weight ω_s is the fraction of all convictions for the crime of interest that take place in state s. We are interested not only in the point value of the above statistic, but also the extent to which it is statistically less than one, as this would imply a lower wrongful conviction rate among convicted defendants of race A than among convicted defendants of race B in the United States for a given crime over our time period of interest.

Using the analogy principle, estimating $\theta_{A,B}$ is ostensibly quite straightforward using the observed realizations, or

$$\hat{\theta}_{A,B} = \sum_{s=1}^{S} \ddot{\omega}_s \frac{EX\ddot{O}N_{A,s}/\ddot{C}_{A,s}}{EX\ddot{O}N_{B,s}/\ddot{C}_{B,s}} \tag{4}$$

where the dots indicate observed realizations. As shown in Section III, in expectation, this statistic should be weakly greater than π_A/π_B.

Calculating and making statistical inference with respect to the above statistic is complicated by two issues. First, while we observe the realized actual number of DNA exonerations for a given crime by race in each state (i.e., $EX\ddot{O}N_{r,s}$ for each race r and state s), as stated in the previous section, our observed convictions for each race (i.e., $\ddot{C}_{r,s}$ for each race r and state s) is not actually the true number of individuals from a given race convicted for a given crime in each state. Rather, we only observe some fraction of all convictions in each state (i.e., those that led to incarceration and reported in the NCRP data). However, if the fraction of convicted individuals we observe within each state is roughly equal across races, or in other words we are not seeing a disproportionate fraction of convicted individuals from one race relative to another within each state, then, as we show below, this will not be an issue. The second complication with respect to estimating $\hat{\theta}_{A,B}$ as described by equation (4) is that among some conviction year cohorts in some states there are zero DNA exonerations of black defendants, leading to a zero in the denominator, making it impossible to compute the statistic in equation (4) for those states.

Given these issues highlighted above, consider the following statistic

$$\theta'_{A,B} = E\left[\sum_{s=1}^{S} \omega_s \frac{\frac{EXON_{A,s}}{\alpha_s C_{A,s}} + \frac{d(EXON_{A,s}, EXON_{B,s})}{\alpha_s (C_{A,s} + C_{B,s})}}{\frac{EXON_{B,s}}{\alpha_s C_{B,s}} + \frac{d(EXON_{A,s}, EXON_{B,s})}{\alpha_s (C_{A,s} + C_{B,s})}}\right] \quad (5)$$

where α_s is a parameter capturing the fraction of all convictions for a given crime in state *s* that we observe in the NCRP data (where it is assumed that we observe roughly this same fraction of cases for both races), and $d(EXON_{A,s}, EXON_{B,s})$ is a function equal to zero when there is at least one DNA exoneration of a defendant of *each race* in state *s* (i.e., $EXON_{r,s} \geq 1$ for *both* races *r*), but is equal to a positive constant δ (to be discussed below) in states when there are zero DNA exonerations of defendants of *either* race. As we show in the Appendix, in expectation, $\theta'_{A,B}$ will provide a measure of π_A/π_B that is weakly biased toward one, or biased toward a null finding of no difference in the wrongful conviction rate across races. The intuition for this is quite clear---in states where $\delta > 0$ an identical noise term is being added to both the top and bottom of a fraction, which will push this fraction closer to one.

Again using the analogy principle, our estimate of, $\theta'_{A,B}$ is then simply

$$\hat{\theta}'_{A,B} = \sum_{s=1}^{S} \ddot{\omega}_s \frac{\frac{E\ddot{X}ON_{A,s}}{\ddot{C}_{A,s}} + \frac{d(E\ddot{X}ON_{A,s}, E\ddot{X}ON_{B,s})}{\ddot{C}_{A,s} + \ddot{C}_{B,s}}}{\frac{E\ddot{X}ON_{B,s}}{\ddot{C}_{B,s}} + \frac{d(E\ddot{X}ON_{A,s}, E\ddot{X}ON_{B,s})}{\ddot{C}_{A,s} + \ddot{C}_{B,s}}} \quad (6)$$

where again the dots indicate observed realizations, and recognizing that our observed convictions in each state are some fraction α_s of all convictions that occurred in that state, or $\ddot{C}_{r,s} = \alpha_s C_{r,s}$ for each race *r* in each state *s*.

As stated above, $d(EXON_{A,s}, EXON_{B,s})$ is a function that equals zero in states where there are one or more DNA exonerations of defendants of *both* races, but $d(EXON_{A,s}, EXON_{B,s})$ will equal a positive constant δ (hereafter referred to as the "Zero Adjustment Parameter") in states where there are no DNA exonerations of defendants of *either* race. Our preferred Zero Adjustment Parameter value is δ = 3.5, which is the mean number of exonerations per state over our sampling window. As can be seen in equation (6), if there is at least one DNA exoneration of defendants of both races in a given state *s*, then the Zero Adjustment Parameter plays no role for that state. On the other hand, in states where there are a positive number of DNA exonerations of defendants from one race but zero DNA exonerations of defendants the other race, the Zero Adjustment Parameter δ divided by the number of reported convictions in that state will add something of proportional magnitude to both the top and the bottom.

So, for example, consider a state where there are two DNA exonerations of defendants of race B and one DNA exoneration of a defendant of race A, and suppose there 500 convictions for each race. The contribution from this state to the summation in equation (6) will equal

$$\frac{\frac{1}{500}+\frac{0}{1000}}{\frac{2}{500}+\frac{0}{1000}}=0.5$$

or in words, this state will contribute 0.5 to the weighted mean being calculated in our test statistic. Alternatively, consider a state where there are two DNA exonerations of defendants of race B and zero DNA exonerations of defendants of race A, and again suppose there 500 convictions for each race. Given a $\delta = 3.5$, the contribution from this state to the summation in equation (6) will equal

$$\frac{\frac{0}{500}+\frac{3.5}{1000}}{\frac{2}{500}+\frac{3.5}{1000}}=0.467$$

or in words, this state will contribute 0.467 to the weighted mean being calculated in our test statistic. Given the above examples, and the fact that any time the Zero Adjustment Parameter is non-zero our estimate will be biased toward one, we feel this is a relatively conservative way to handle the zeros problem. While $\delta = 3.5$ seems to be an obvious candidate as the mean number of DNA exonerations per state, we try larger values of δ as well to show robustness to different values. Smaller values of δ seem to be problematic as even a few exonerations for one race (when there are none for the other) can move the estimate quite substantially.

In estimating our statistics, we only include states for which our data can provide potentially informative results. Therefore, in our analysis of rape, we only include states in which there was at least one DNA exoneration for rape (of a defendant of either race), which limits our sample to 25 states (see Table A-1 in Appendix for included states). Similarly, in our analysis of murder, we only include states in which there was at least one DNA exoneration for murder (again of a defendant of either race), which includes 23 states. We do this since we feel that in states with no DNA exonerations for the crime of interest our procedure simply cannot be informative about the relative rates of wrongful convictions across races in these states (i.e., in states with no DNA exonerations, our procedure provides no information that could change any prior belief about the relative rate of wrongful convictions across races).

Finally, in addition to the estimated value of our parameter of interest as given by equation (6), we want to test whether our estimated parameter is significantly less than one, as this would suggest that the wrongful conviction rate for convicted defendants of race A (the race in the numerator of equation (6)) is truly less than the wrongful conviction rate for defendants of race B (the race in the denominator of equation (6)). To do this test, we use a bootstrap approach to test the null hypothesis that $\pi_A/\pi_B = 1$ (i.e., that the wrongful conviction rates are equal across races). In particular, each bootstrap sample draw is a random sample with replacement of convictions from the NCRP data. We then then randomly assign whether each convict in each bootstrap sample is an "exonerated wrongful conviction," where the likelihood that any given convict within a given state in the bootstrap sample is an "exonerated wrongful conviction" is forced to be equal across races. Specifically, in each bootstrap sample, the likelihood of being an "exonerated wrongful conviction" for each convict in any given state (regardless of race) is determined by the realization of a single random draw from a Bernoulli distribution with a mean exoneration rate equal to the true overall average exoneration rate for that state over the relevant conviction year cohorts.

For each bootstrap sample, we then compute the statistic described in equation (6) above using these randomly determined synthetic "exonerations." We do this procedure for one thousand different bootstrap samples and compute our p-value to be the fraction of times the calculated statistics coming from the bootstrap samples are less than the actual statistic we estimate using the real data. In words, one can interpret the p-values shown in the tables below as indicating the likelihood of observing a value of the estimated statistic as low as what we find if the wrongful conviction rate and likelihood of exoneration conditional on wrongful conviction is the same across races.

VI - Results

Table 1 shows our estimates of $\theta'_{W,B}$ and $\theta'_{B,W}$ for rape as described by equation (6) under a variety of different subsamples and parameterizations (where subscript "W" refers to whites and subscript "B" refers to black). In words, the top panel shows our test for whether the wrongful conviction rate among *white* rape defendants is less than the wrongful conviction rate among *black* rape defendants, while the bottom panel shows the reverse (i.e., shows our test for whether the wrongful conviction rate among *black* rape defendants is less than the wrongful conviction rate for rape among *white* defendants). Our estimates are shown with respect to three different Zero Adjustment Parameter (i.e., $\delta = 3.5$, $\delta = 5$, $\delta = 15$) across the three columns, and four different subsamples: (i) Uses DNA exonerations only and conviction cohorts from 1983-1997, (ii) Uses any kind of exoneration and conviction cohorts from 1983-1997, (iii) Uses DNA exonerations only but limit conviction cohorts to 1983-1989 (defendants convicted prior to first DNA exoneration), and (iv) Uses DNA exoneration only but limit conviction cohorts to 1990-1997 (defendants convicted after first DNA exoneration).

Looking first at the top row of column (1), we see that when we use only DNA exonerations, conviction cohorts from 1983 – 1997, and a $\delta = 3.5$, our estimated parameter is 0.63. The interpretation of this estimate is that over these conviction cohorts, *the wrongful conviction rate among white rape defendants is less than two-thirds what it is among black rape defendants*. The bootstrapped p-value shown below this estimate suggests that the likelihood that a value this small relative to one would arise if the wrongful conviction rate among white rape defendants were actually equal to the wrongful conviction rate among black rape defendants is less than four in one hundred. Moving across columns in the top row shows that our estimate of this parameter is relatively unaffected by the value we use for the Zero Adjustment Parameter δ.

One concern with using only DNA exonerations is that innocent whites are more likely to be exonerated by other methods more quickly, precluding them from being exonerated by DNA. This would cause us to underestimate the wrongful conviction rate for whites relative to blacks. However, our results change very little if we use all exonerations rather than just DNA exonerations. As can be seen in row (ii) of Table 1, even when using all exonerations rather than just DNA exonerations, our estimated statistic remains between 0.60 and 0.67, and in all cases the p-values continue to suggest that it would be very unlikely to find these results if the wrongful conviction rate among white rape defendants were actually equal to the wrongful conviction rate among black rape defendants.

Interestingly, when we divide the sample up into using only the 1983-1989 cohorts or only the 1990-1997 cohorts, the estimated parameters converge a little toward one, especially for the 1990-1997 cohorts. However, in both cases the p-values continue to suggest that it is still relatively unlikely that such values would arise if indeed the wrongful conviction rate among white rape defendants were equal to the wrongful conviction rate among black rape defendants At first look, one might be concerned that the estimated parameters coming from both of the conviction cohort subgroups are closer to one than the estimated parameter for all conviction cohorts combined. The reason behind this seeming conundrum is that the Zero Correction Parameter takes on a non-zero value more often when we take the more limited sets of conviction cohorts, since with fewer conviction cohorts there are more states in which there are no DNA exonerations for members of one race or another. Because a positive Zero Adjustment Parameter biases our estimate toward one (as shown in the Appendix), this accounts for the estimated parameter being closer to one in the two conviction cohort subgroups than when the parameter is estimated using all conviction cohorts. In other words, using less data will bias us toward a null finding, which in this case is an estimated value of one.

Relatedly, the fact that the estimated parameter is closer to one for the 1990-1997 cohorts relative to the 1983-1989 cohorts can be due to two things. First, it could be that the underlying wrongful conviction rates for rape across races are closer to equal among those in the later conviction cohorts than those in the earlier cohorts. Second, it could be that because there are fewer DNA exonerations among the 1990-1997 conviction cohorts than among the 1983-1989 conviction cohorts, the Zero Adjustment Parameter is positive for more states among the later conviction cohorts, causing the estimated statistic to be more biased toward one in the later conviction cohort subsample.

Looking at the lower panel of Table 1, we see no evidence that the wrongful conviction rate for rape among *black* rape defendants is less than the wrongful conviction rate for rape among *white* defendants. Notably, none of the point estimates are even less than one. Given the findings in the top panel of Table 1, this is not surprising as it essentially has to be the case---i.e., given the top panel suggests the wrongful conviction rate among *whites* convicted for rape is less than the wrongful conviction rate among *blacks* convicted for rape it cannot also be true that the wrongful conviction rate among *blacks* convicted for rape is less than the wrongful conviction rate among *whites* convicted for rape. However, we show these results for two reasons. First, while initial intuition might suggest the results in the lower panel should just be the inverse of the results in the upper panel, Table 1 reveals this is not actually the case. Second, as will be seen below in our results with respect to murder, if we did not find evidence that suggested the wrongful conviction rates among *white* defendants was less than it was among *black* defendants, this would not necessarily tell us whether the wrongful conviction rates among *black* defendants was less than it was among *white* defendants---these tests need to be done separately.

Turning now to our results with respect to murder, we can look at Table 2. Table 2 is structured the same as Table 1 but for murder rather than rape. If we again start with the top row of column (1), we see that when using only DNA convictions, conviction cohorts from 1983-1997, and a Zero Adjustment Parameter equal to 3.5, our estimated test statistic suggests that the ratio of the *white* wrongful conviction rate for murder to the *black* wrongful conviction rate for murder is no greater than 1.69. As can be seen in the rest of the estimates shown the top panel of Table 2, these results are again relatively unchanged by using different Zero Adjustment Parameters, using all exonerations (rather than just DNA exonerations), or taking subsets of the conviction cohorts. All of the estimated statistics are well above one.

In general, the estimates in the top panel of Table 2 provide no evidence that the wrongful conviction rate among *white* defendants convicted for murder is less than the wrongful conviction rate among *black* defendants convicted for murder. However, it is again worth noting that these test statistics are simply giving an *upper bound* on the ratio of the *white* wrongful conviction rate for murder relative to the *black* wrongful conviction rate for murder. Therefore, as alluded to above, even though our estimated test statistics all exceed one in the top panel of Table 2, these results do not necessarily show that the *white* wrongful conviction rate for murder is greater than the *black* wrongful conviction rate for murder, nor does it even definitively exclude the possibility that the *white* wrongfully conviction rate for murder is less than the *black* wrongful conviction rate for murder. Rather, it is simply inconclusive on these questions.

Given these results in the upper panel of Table 2 though, it is important to consider the bottom panel of Table 2, which directly shows our estimated test statistics for whether *black* defendants are less likely to be wrongfully convicted for murder than *white* defendants. Interestingly, if we again look at column (1) of the top row of the *lower panel* of Table 2, when using only DNA convictions, conviction cohorts from 1983-1997, and a Zero Adjustment Parameter equal to 3.5, our estimated test statistic suggests that the ratio of the *black* wrongful conviction rate for murder to the *white* wrongful conviction rate for murder is no greater than 1.26. Looking across the different specifications, the vast majority of point estimates are again above one. Only when the population is limited to defendants convicted between 1983 and 1989 are the estimated statistics less than one, albeit they are still very close to one (0.96 and above). Moreover, the bootstrapped p-values reveal these estimated statistics are never even close to being statistically less one at even the 10 percent level. So, our results shown in the lower panel of Table 2 also provide no evidence that suggests that the *black* wrongful conviction rate for murder is lower than the *white* wrongful conviction rate for murder.

One might be surprised at the results coming out of Table 2 given Alessina and La Ferrara's (2014) findings showing that among those sentenced to death for a murder conviction, black defendants were more likely to have their convictions overturned than white defendants (at least when there was a white victim). Again though, we want to reiterate that our results for murder are simply inconclusive---they do not necessarily imply equal wrongful conviction rates across races for murder since what we estimate is an upper bound. Moreover, Alessina and La Ferrara's (2014) sample consisted only of murder convictions that led to the death penalty, while our sample consists of all murder convictions. As suggested earlier, it is also certainly possible that wrongful convictions for murder are relatively similar across races, but wrongfully convicted black defendants are more likely to be given a death sentence than wrongfully convicted white defendants (particularly when the victim is white). Hence, our results are certainly not in conflict with Alessina and La Ferrara's (2014) findings.

We can get a further sense of how robust the results shown in Tables 1 and 2 are across states by looking at Figures 2a and 2b.[6] Figure 2a shows the state specific contributions to our estimated test statistics shown in column (1) of the top row of the top panels in Tables 1 and 2. In other words, Figure 2a shows our estimate of the upper bound on the wrongful conviction rate among *white* defendants relative to *black* defendants for rape and murder in each state over all conviction cohorts from 1983-1997 using only DNA exonerations (and a Zero Adjustment Parameter of 3.5). The grey squares are the results for rape, the darker diamonds are the results for murder. As can be seen, for 20 out of the 25 (80 percent) states in which there was at least one DNA exoneration for rape among these conviction cohorts, our estimated statistic was less than 0.85. So while the top panel of Table 1 presented the weighted average across all of these state specific estimated statistics, Figure 2a makes clear that the results in the top panel of Table 1 were not simply being driven by one particular state. By contrast, the black diamonds in Figure

[6] See Appendix Tables A1 and A2 for the actual numbers from Figures 2a and 2b and their corresponding states.

2a show that in only 7 out of the 23 states that had a DNA exoneration for murder among the 1983-1997 conviction cohorts was our estimated statistic less than 0.85.

Similarly, Figure 2b shows our estimate of the upper bound on the wrongful conviction rate among *black* defendants relative to *white* defendants for rape and murder by state over all conviction cohorts from 1983-1997 using only DNA exonerations (i.e., the state specific contributions to the estimated test statistics shown in column (1) of the top row of the bottom panels in Tables 1 and 2). As can be seen from the grey squares, in almost all states in our sample the estimated statistic is greater than one. Again, this should be expected given the results for rape in Figure 2a. With respect to murder though, in 14 out of the 23 states in our sample (60 percent), our estimated statistic is less than 0.85. However, there are several states in which our estimated statistic with respect to murder is close to 2 or higher, which is why when we take the weighted average across all states as shown in the top row of column (1) in the bottom panel of Table 2, our resulting test statistic is still greater than one.

In general, the results shown in Figures 2a and 2b show that our findings that suggest wrongful conviction for rape is significantly less likely among *white* defendants than *black* defendants are quite robust across states. It does not appear that one or two particular states, or states located in only one region of the country, are driving our results. On the other hand, these figures also further emphasize that our estimation procedure provides little evidence to reject the null hypothesis that the wrongful conviction rate with respect to murder is similar across races.

As a final check, Table 3 shows the robustness of our results to excluding any given conviction cohort. Specifically, the first column of numbers in the first row in Table 3 again shows our estimated upper bound on the ratio of *white to black* wrongful conviction rates for rape using the 1983-1997 conviction cohorts, DNA exonerations only, and a Zero Adjustment Parameter $\delta = 3.5$ (i.e., the estimated statistic reported in the top row of column (1) in Table 1). The second column of numbers shows the standard deviation of this estimated parameter when estimated using sequential subsets of conviction cohorts where one conviction cohort is dropped in each iteration. The third and fourth columns show the minimum and the maximum of this estimated statistic that arise over these successive iterations. As can be seen, it does not appear that our result is being driving by any particular year, as little variation arises in our estimate over these different iterations. Moreover, our minimum and maximum estimated statistics are always well below one over all of these sequential iterations.

The other rows in Table 3 show the results from analogous exercises done for our estimated upper bound on the ratio of *white to black* wrongful conviction rates for murder, and our estimated upper bound on the ratio of *black to white* wrongful conviction rates for rape and murder. There is a little more variation in these estimates across subsamples, but again, the minimum and maximum of these estimated statistics are greater than one across all iterations, providing little support for the hypothesis that the wrongful conviction rate among *blacks* for rape is *lower* than it is among *whites* for rape, or that the wrongful conviction rate with respect to murder is different across races.

VII – Discussion of Key Assumption and Interpretation

If one is willing to assume that the likelihood of a DNA exoneration for a wrongfully convicted defendant is independent of the race and strength of evidence against the wrongfully convicted defendant (at least among those convicted for the same crime, in the same state, with the same plea status), then the results above provide strong evidence that the rate of wrongful convictions among white defendants convicted for rape is significantly less than it is among black defendants convicted for rape.

As discussed at the end of Section II, we think the assumption made above is reasonable given what we know about the DNA exoneration process, but it is admittedly hard to provide direct evidence for this assumption. One potential concern is that the likelihood of being exonerated (even by DNA evidence) for innocent defendants likely falls dramatically after being released from prison, and exonerations take time. Indeed, 75 percent of rape and murder DNA exonerations took six or more years after conviction. To the extent to which innocent black defendants convicted for rape are given longer sentences than innocent white defendants convicted for rape may mean innocent blacks will be more likely than innocent whites to be in prison sufficiently long to be exonerated, which would violate the assumption discussed above. However, evidence for this concern is not very strong. For example, among those admitted to prison between 1983 and 1997 and had their sentence reported National Corrections Reporting Program data, the 25th, 50th, and 75th percentiles of the sentence length distribution are the same for black and white defendants convicted for rape (96 months, 240 months, and life/death respectively).[7] Similarly, the 25th, 50th, and 75th percentiles of the sentence length distribution are almost the same for black and white defendants convicted for murder (25th percentile 360 months for whites and 336 months for blacks, 50th and 75th percentiles are life/death sentences for both blacks and whites). So, as the above distributions of sentence lengths make clear, among those incarcerated for rape or murder, the sentences are generally long enough among convicted defendants of both races for the DNA exoneration process to play out.

It is also worth pointing out that one piece of evidence arguably in favor of the assumption that the DNA exoneration process is independent of race (within state and plea status), is that under this assumption our procedure suggests a significant racial bias against black defendants with respect to wrongful conviction for rape, but *not* for murder. If the key assumption discussed above is incorrect because advocacy groups like the Innocence Project were more likely to take on cases involving black

[7] In doing this analysis, we topcoded sentences at 50 years (600 months), as well as coded life sentences and death sentences to be 50 years. It may be surprising that sentence length distributions are so similar across races. However, note that these sentences are implicitly being conditioned on type of crime (both of a very serious nature), as well as being conditioned on the defendant being sentenced to incarceration.

defendants, or judges were more likely to grant hearings to black defendants, why would this only be true for rape defendants but not murder defendants? Rather, we think it is more plausible that racial bias with respect to wrongful convictions is stronger when it comes to rape cases than murder cases because of a greater prevalence of racially biased eyewitness error in rape cases than murder cases. As discussed previously, recent work by the National Academy of Sciences (2014) documents concerns about errors in witness identification of perpetrators, particularly when it comes to black suspects. Moreover, witness identification appears to be a source of evidence far more often with respect to rape convictions than murder convictions. Indeed, according to the National Registry of Exonerations data, witness identification played a role in convicting the vast majority of rape defendants later exonerated by DNA evidence among both races in our sample (83 percent for black defendants, 72 percent of white defendants), but it was a factor in the conviction of a much smaller minority of murder defendants later exonerated by DNA evidence (23 percent of black defendants, 19 percent of white defendants).

This fact that eyewitness testimony played in a role in the conviction of such a high fraction of the rape defendants later exonerated by DNA may cause one to worry that advocacy groups looking to secure DNA exonerations may be disproportionately focusing their efforts on cases with this type of evidence (though again we have no evidence that this is the case). If innocent black individuals are more likely to be mis-identified as the than white individuals in rape cases, then advocacy groups disproportionately directing their efforts at these types of cases might implicitly cause the DNA exoneration process to be racially biased against white defendants. However, for our interpretation of our results to be invalid, not only would advocacy groups have to be more likely to pursue exonerations in rape cases where eyewitness testimony played a role in conviction, but for overall wrongful rates to be equal across races, there must then be some other way in which black defendants are *significantly less likely* to be wrongfully convicted for rape than white defendants *and* wrongful conviction advocacy groups must be *less* prone to take up these types of cases. Again, there is no obvious reason for this to be true.

In the end though, we simply do not have definitive evidence regarding whether the DNA exoneration process is racially biased or not. However, like Alesina and LaFerrara (2014), we think that we are considering an assumption that arguably seems to be a natural place to start. Alesina and LaFerrara's interpretation of their results requires the assumption that higher courts can only improve upon the accuracy of lower courts and therefore reduce racial bias. Given the lack of any evidence regarding the relative racial bias of judges in upper courts versus lower courts, their assumption does not seem unreasonable even though one could conceive of reasons why it may not hold. Arguably, our key assumption is even less restrictive than Alesina and La Ferrara's in that it is clear that exoneration by DNA evidence does require a large component of random luck, and we are simply considering a "middle" ground that this luck operates similarly across all innocent defendants within the same state with the same plea status. Moreover, related to the discussion in the previous paragraph, if one were to think our results are being driven by a higher likelihood of DNA exoneration for innocent black defendants than innocent white defendants in the same state with the same plea status, not only would one have to believe that this greater likelihood was very substantial for rape cases (e.g., roughly 1.5 times greater), but one would also have to think about why this racial bias in the DNA exoneration process would occur in rape cases but not murder cases.

Finally, given the falling cost and increased use of DNA testing, there may well be fewer wrongful convictions (of both races) in recent years than amongst those convicted in the 1980s and 1990s. Indeed, this may well be one of the reasons for the downward trend in exonerations by conviction cohort since the late 1980s as shown in Figure 1b. How might this affect the interpretation of our results? For one, as we discuss above, what we are estimating is the average ratio of relative wrongful conviction rates across races among those convicted in the 1980s thru the 1990s. To the extent there are fewer wrongful convictions in more recent years would undoubtedly be a good thing, but doesn't necessarily change the importance of our results. Moreover, even if the *overall* frequency of wrongful convictions has fallen substantially among cohorts convicted in the last decade, this does not necessarily mean that the *relative* frequency of wrongful convictions across races has changed.

VIII - Conclusions

This paper develops and estimates a ratio statistic based on DNA exoneration rates that we think provides the first empirical test for detecting differences in wrongful conviction rates across races. While our estimates are generally inconclusive with respect to murder, under some assumptions regarding the DNA exoneration process, they are quite strong with respect to rape. Indeed, among those convicted for rape between 1983-1997, our results suggest that the wrongful conviction rate among black defendants was more than one and a half times higher than it was among white defendants.

We think these results are quite profound, as they directly imply that among those convicted for rape in the latter decades of the 20^{th} century, the American legal system was biased against black Americans in the sense that black Americans are disproportionately bearing the burden of errors in our judicial system through being convicted and punished for rape crimes they did not commit. To the extent to which these wrongfully convicted individuals are being convicted and incarcerated in lieu of the actual perpetrators of these crimes, and these perpetrators are of the same race as those wrongfully convicted, these results also may suggest that there are a disproportionate number of black rapists failing to be punished for their crimes.[8] The fact that both of these failures of the justice system are disproportionately falling on black communities can no doubt lessen trust in the legitimacy of the American justice system in these black communities and indeed all American communities.

How to repair this bias in the judicial system is not obvious. However, as alluded to previously, witness mis-identification of the perpetrator appears to be a likely source for much of the racial bias in wrongful conviction for rape. Getting actors in the judicial system to recognize the potentially racially biased outcomes associated with witness identification of perpetrators as a form of evidence, and to understand the broader implications of this bias, seem to be important first steps in mitigating the apparent racial imbalance in wrongful conviction rates for rape.

[8] Note, this does not necessarily follow if a higher fraction of rapes committed by white perpetrators go unsolved.

Appendix

Consider the following proposition:

Proposition –

(i) If $\frac{\pi_{A,s}}{\pi_{B,s}} \leq 1$, then $\frac{\pi_A}{\pi_B} \leq \frac{\frac{E[EXON_{A,s}]}{\alpha_s C_{A,s}} + \frac{\delta}{\alpha_s (C_{A,s}+C_{B,s})}}{\frac{E[EXON_{B,s}]}{\alpha_s C_{B,s}} + \frac{\delta}{\alpha_s (C_{A,s}+C_{B,s})}}$

(ii) If $1 < \frac{\pi_{A,s}}{\pi_{B,s}}$, then $\frac{\frac{E[EXON_{A,s}]}{\alpha_s C_{A,s}} + \frac{\delta}{\alpha_s (C_{A,s}+C_{B,})s}}{\frac{E[EXON_{B,s}]}{\alpha_s C_{B,s}} + \frac{\delta}{\alpha_s (C_{A,s}+C_{B,})s}} < \frac{\pi_A}{\pi_B}$

In words, this proposition states that if the ratio of wrongful conviction rates for defendants of race A relative to defendants of race B is less than or equal to one, our test statistic is upwardly biased, while if the ratio of wrongful conviction rates for defendants of race A relative to defendants of race B is greater than one, our test statistic is downwardly biased.

To prove this proposition, first consider part (i). As shown in Section II,

$$\frac{\pi_{A,s}}{\pi_{B,s}} \leq \frac{E\left[EXONRT_{A,s}\right]}{E\left[EXONRT_{B,s}\right]}$$

Therefore, to prove part (i) of the above proposition, we simply need to show

$$\frac{E\left[EXONRT_{A,s}\right]}{E\left[EXONRT_{B,s}\right]} \leq \frac{\frac{E[EXON_{A,s}]}{\alpha_s C_{A,s}} + \frac{\delta}{\alpha_s (C_{A,s} + C_{B,s})}}{\frac{E[EXON_{B,s}]}{\alpha_s C_{B,s}} + \frac{\delta}{\alpha_s (C_{A,s} + C_{B,s})}}$$

To prove the above statement, first let $\delta_s{}' = \frac{\delta}{\alpha_s (C_{A.s}+C_{B,s})}$, and note that $E\left[EXONRT_{r,s}\right] = \frac{EXON_{r,s}}{C_{r,s}}$. Given this, the above expression can be written

$$\frac{\frac{E[EXON_{A,s}]}{C_{A,s}}}{\frac{E[EXON_{B,s}]}{C_{B,s}}} \leq \frac{\frac{E[EXON_{A,s}]}{\alpha_s C_{A,s}} + \delta'}{\frac{E[EXON_{B,s}]}{\alpha_s C_{B,s}} + \delta'}$$

Re-arranging we get

$$\frac{E[EXON_{A,s}]}{C_{A,s}} \frac{E[EXON_{B,s}]}{\alpha_s C_{B,s}} + \frac{E[EXON_{A,s}]}{C_{A,s}} \delta' \leq \frac{E[EXON_{A,s}]}{\alpha_s C_{A,s}} \frac{E[EXON_{B,s}]}{C_{B,s}} + \frac{E[EXON_{B,s}]}{C_{B,s}} \delta'$$

Cancelling like terms we get

$$\frac{E[EXON_{A,s}]}{C_{A,s}}\delta' \leq \frac{E[EXON_{B,s}]}{C_{B,s}}\delta'$$

which reduces to

$$E\left[EXONRT_{A,s}\right] \leq E\left[EXONRT_{B,s}\right]$$

or

$$\frac{E\left[EXONRT_{A,s}\right]}{E\left[EXONRT_{B,s}\right]} \leq 1$$

which is true if $\frac{\pi_{A,s}}{\pi_{B,s}} \leq 1$, thus proving part (i).

Now consider part (ii) of the above Proposition. As implied by the discussion in Section II,

$$\frac{\pi_{B,s}}{\pi_{A,s}} \leq \frac{E\left[EXONRT_{B,s}\right]}{E\left[EXONRT_{A,s}\right]}$$

which in turn implies

$$\frac{E\left[EXONRT_{A,s}\right]}{E\left[EXONRT_{B,s}\right]} \leq \frac{\pi_{A,s}}{\pi_{B,s}}$$

Therefore, to prove part (ii) of the above proposition, we simply need to show

$$\frac{\frac{E[EXON_{A,s}]}{\alpha_s C_{A,s}} + \frac{\delta}{\alpha_s(C_{A,s} + C_{B,s})}}{\frac{E[EXON_{B,s}]}{\alpha_s C_{B,s}} + \frac{\delta}{\alpha_s(C_{A,s} + C_{B,s})}} \leq \frac{E\left[EXONRT_{A,s}\right]}{E\left[EXONRT_{B,s}\right]}$$

To prove the above statement, again let ${\delta_s}' = \frac{\delta}{\alpha_s(C_{A.s}+C_{B,s})}$, and note that $E\left[EXONRT_{r,s}\right] = \frac{EXON_{r,s}}{C_{r,s}}$. Given this, the above expression can be written

$$\frac{\frac{E[EXON_{A,s}]}{\alpha_s C_{A,s}} + \delta'}{\frac{E[EXON_{B,s}]}{\alpha_s C_{B,s}} + \delta'} \leq \frac{\frac{E[EXON_{A,s}]}{C_{A,s}}}{\frac{E[EXON_{B,s}]}{C_{B,s}}}$$

Re-arranging we get

$$\frac{E[EXON_{A,s}]}{\alpha_s C_{A,s}}\frac{E[EXON_{B,s}]}{C_{B,s}} + \frac{E[EXON_{B,s}]}{C_{B,s}}\delta' \leq \frac{E[EXON_{A,s}]}{C_{A,s}}\frac{E[EXON_{B,s}]}{\alpha_s C_{B,s}} + \frac{E[EXON_{A,s}]}{C_{A,s}}\delta'$$

Cancelling like terms we get

$$\frac{E[EXON_{B,s}]}{C_{B,s}}\delta' \leq \frac{E[EXON_{A,s}]}{C_{A,s}}\delta'$$

which reduces to

$$E\left[EXONRT_{B,s}\right] \leq E\left[EXONRT_{A,s}\right]$$

or

$$1 \leq \frac{E\left[EXONRT_{A,s}\right]}{E\left[EXONRT_{B,s}\right]}$$

which is true if $1 \leq \frac{\pi_{A,s}}{\pi_{B,s}}$, thus proving part (ii).

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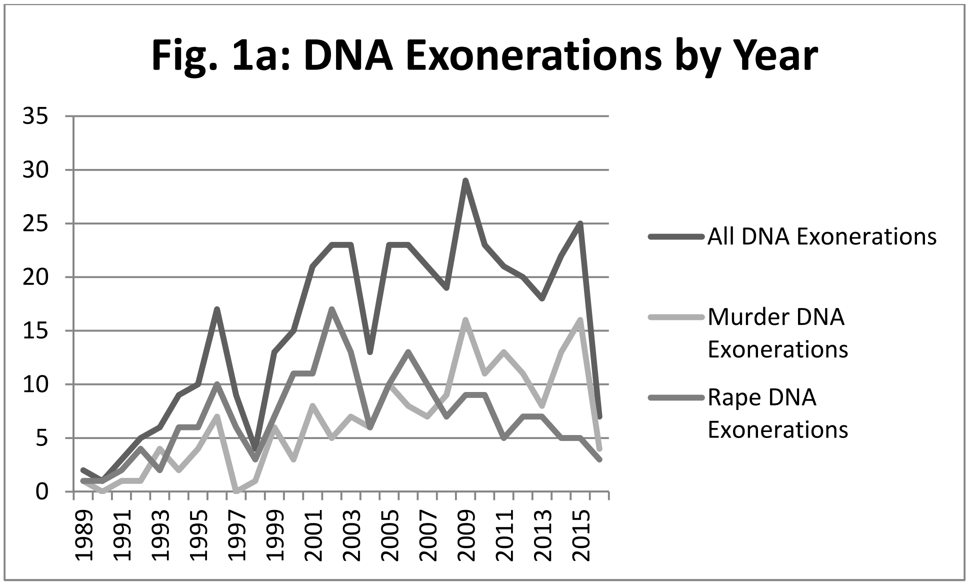


Fig. 1a: DNA Exonerations by Year
35
30
25
20
15
10
5
0
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
All DNA Exonerations
Murder DNA Exonerations
Rape DNA Exonerations

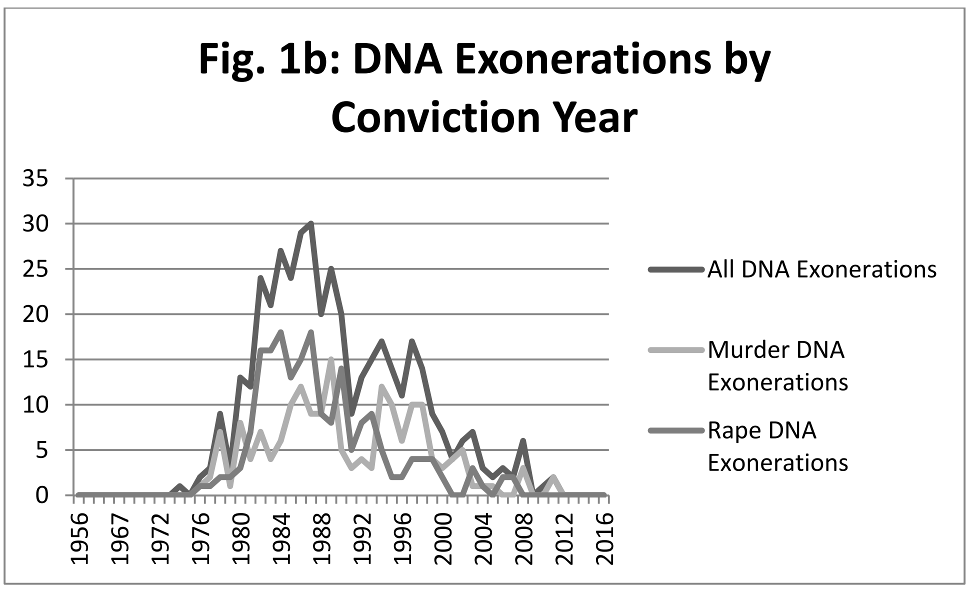


Fig. 1b: DNA Exonerations by Conviction Year
35
30
25
20
15
10
5
0
1956
1967
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
All DNA Exonerations
Murder DNA Exonerations
Rape DNA Exonerations

Table 1: Estimated Upper Bound on Ratio of Wrongful Conviction Rate for Rape Across Races

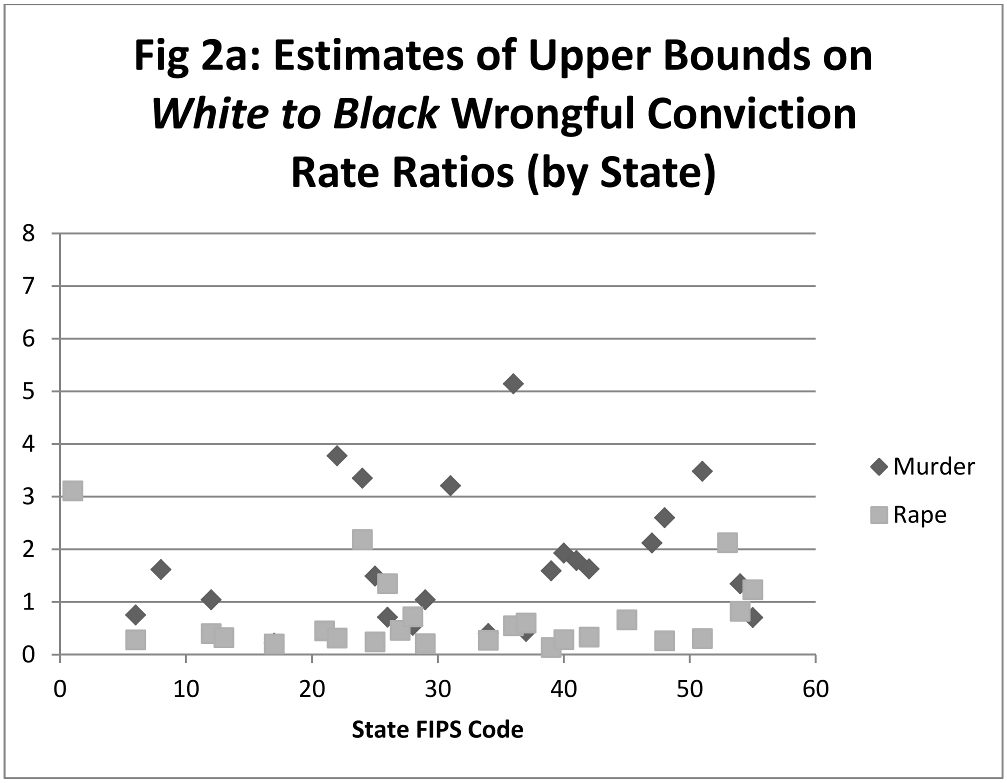
	Zero Adjustment Parameter		
	δ = 3.5	**δ = 5**	**δ = 15**
	(1)	**(2)**	**(3)**
White to Black Ratio (Estimate of θ'_{WB})			
(i) Using DNA Exonerations Only	0.63	0.62	0.66
(1983 - 1997 Convictions)	*p-val = 0.040*	*p-val = 0.030*	*p-val = 0.033*
(ii) Using any type of Exoneration	0.67	0.63	0.60
(1983 - 1997 Convictions)	*p-val = 0.000*	*p-val = 0.006*	*p-val = 0.004*
(iii) Using DNA Exonerations Only	0.68	0.70	0.78
(1983 - 1989 Convictions)	*p-val = 0.002*	*p-val = 0.002*	*p-val = 0.010*
(iv) Using DNA Exonerations Only	0.87	0.87	0.91
(1990 - 1997 Convictions)	*p-val = 0.038*	*p-val = 0.045*	*p-val = 0.106*
Black to White Ratio (Estimate of θ'_{BW})			
(i) Using DNA Exonerations Only	2.97	2.76	2.43
(1983 - 1997 Convictions)	*p-val = 0.986*	*p-val = 0.984*	*p-val = 0.966*
(ii) Using any type of Exoneration	2.70	2.61	2.48
(1983 - 1997 Convictions)	*p-val = 0.999*	*p-val = 0.998*	*p-val = 0.996*
(iii) Using DNA Exonerations Only	2.47	2.23	1.86
(1983 - 1989 Convictions)	*p-val = 0.998*	*p-val = 0.996*	*p-val = 0.977*
(iv) Using DNA Exonerations Only	1.73	1.51	1.17
(1990 - 1997 Convictions)	*p-val = 0.917*	*p-val = 0.828*	*p-val = 0.489*

Note: p-val refers to bootstrapped probability that a parameter value less than the estimated parameter value arises when the wrongful conviction rate and likelihood of exoneration conditional on innocence is set to be equal across races. See text for details.

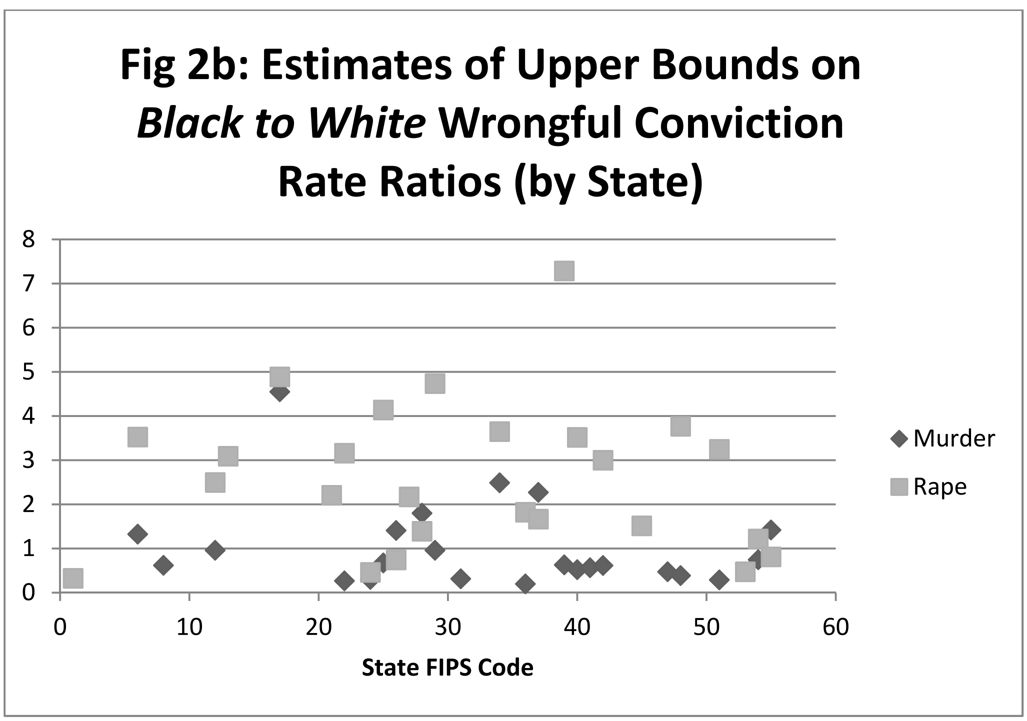
Table 2: Estimated Upper Bound on Ratio of Wrongful Conviction Rate for Murder Across Races

	Zero Adjustment Parameter		
	δ = 3.5	**δ = 5**	**δ = 15**
	(1)	**(2)**	**(3)**
White to Black Ratio (Estimate of θ'_{WB})			
(i) Using DNA Exonerations Only	1.69	1.67	1.64
(1983 - 1997 Convictions)	*p-val = 0.731*	*p-val = 0.754*	*p-val = 0.778*
(ii) Using any type of Exoneration	1.72	1.70	1.67
(1983 - 1997 Convictions)	*p-val = 0.980*	*p-val = 0.981*	*p-val = 0.979*
(iii) Using DNA Exonerations Only	1.50	1.43	1.33
(1983 - 1989 Convictions)	*p-val = 0.708*	*p-val = 0.699*	*p-val = 0.660*
(iv) Using DNA Exonerations Only	1.71	1.63	1.54
(1990 - 1997 Convictions)	*p-val = 0.838*	*p-val = 0.839*	*p-val = 0.841*
Black to White Ratio (Estimate of θ'_{BW})			
(i) Using DNA Exonerations Only	1.26	1.25	1.25
(1983 - 1997 Convictions)	*p-val = 0.589*	*p-val = 0.638*	*p-val = 0.711*
(ii) Using any type of Exoneration	1.33	1.33	1.32
(1983 - 1997 Convictions)	*p-val = 0.802*	*p-val = 0.822*	*p-val = 0.829*
(iii) Using DNA Exonerations Only	0.97	0.96	0.96
(1983 - 1989 Convictions)	*p-val = 0.165*	*p-val = 0.169*	*p-val = 0.213*
(iv) Using DNA Exonerations Only	1.51	1.35	1.14
(1990 - 1997 Convictions)	*p-val = 0.727*	*p-val = 0.662*	*p-val = 0.517*

Note: p-val refers to bootstrapped probability that a parameter value less than the estimated parameter value arises when the wrongful conviction rate and likelihood of exoneration conditional on innocence is set to be equal across races. See text for details.



Note: These plots correspond to the state specific contributions to the statistic calculated in the top row of top panel in column (1) of Tables 2 and 3.



Note: These plots correspond to the state specific contributions to the statistic calculated in the top row of bottom panel in column (1) of Tables 2 and 3.

Table 3: Sensitivity of Estimated Ratio of Wrongful Conviction Rates to Exclusion of Each Year (Conviction Cohorts 1983-1997, DNA Exonerations Only, δ = 3.5)

	Actual Estimate	Variation in Estimate Arising From Excluding Each Particular Year		
		Std. Dev.	**Min**	**Max**
White to Black Ratio (Estimate of θ'_{WB})				
Rape	0.63	0.03	0.59	0.68
	p-val = 0.040			
Murder	1.69	0.14	1.74	2.26
	p-val = 0.731			
Black to White Ratio (Estimate of θ'_{BW})				
Rape	2.97	0.13	2.65	3.03
	p-val = 0.986			
Murder	1.26	0.13	1.02	1.64
	p-val = 0.589			

Table A1 - Estimates of Upper Bounds on White to Black Wrongful Conviction Ratios (Corresponds to Figure 2a)

State Abbr.	FIPS Code	Estimate of θ'_{WB} Rape	Estimate of θ'_{WB} Murder
AL	1	3.11	
CA	6	0.28	0.76
CO	8		1.62
FL	12	0.40	1.04
GA	13	0.32	
IL	17	0.20	0.22
KY	21	0.45	
LA	22	0.32	3.78
MD	24	2.19	3.35
MA	25	0.24	1.49
MI	26	1.35	0.71
MN	27	0.46	
MS	28	0.72	0.56
MO	29	0.21	1.04
NE	31		3.21
NJ	34	0.27	0.40
NY	36	0.55	5.15
NC	37	0.60	0.44
OH	39	0.14	1.59
OK	40	0.28	1.93
OR	41		1.79
PA	42	0.33	1.63
SC	45	0.66	
TN	47		2.12
TX	48	0.27	2.60
VA	51	0.31	3.48
WA	53	2.13	
WV	54	0.82	1.35
WI	55	1.24	0.71

Table A2 - Estimates of Upper Bounds on Black to White Wrongful Conviction Ratios (Corresponds to Figure 2b)

State Abbr.	FIPS Code	Estimate of θ'_{BW} Rape	Estimate of θ'_{BW} Murder
AL	1	0.32	
CA	6	3.52	1.32
CO	8		0.62
FL	12	2.49	0.96
GA	13	3.09	
IL	17	4.88	4.55
KY	21	2.20	
LA	22	3.16	0.26
MD	24	0.46	0.30
MA	25	4.14	0.67
MI	26	0.74	1.41
MN	27	2.17	
MS	28	1.39	1.80
MO	29	4.73	0.96
NE	31		0.31
NJ	34	3.65	2.49
NY	36	1.82	0.19
NC	37	1.66	2.27
OH	39	7.28	0.63
OK	40	3.52	0.52
OR	41		0.56
PA	42	3.00	0.61
SC	45	1.51	
TN	47		0.47
TX	48	3.76	0.38
VA	51	3.24	0.29
WA	53	0.47	
WV	54	1.21	0.74
WI	55	0.81	1.42