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

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Abstract: Under the assumption that the likelihood of exoneration for a wrongfully convicted white defendant is equal to or greater than the likelihood of exoneration for a wrongfully convicted black defendant, we show that the expected value of the *ratio* of the exoneration rate for white convicts relative to the exoneration rate for black convicts convicted in the same year for the same crime provides an upper bound on the ratio of the wrongful conviction rate for whites relative to blacks for that crime. Our estimates of this statistic using exoneration and conviction data from 1986-2006 reveal that the wrongful conviction rate for sexual assault among black defendants is at least three times higher than it is for white defendants. Our estimates for murder are inconclusive.

Keywords: Wrongful convictions; Racial Bias; Judicial Bias; Exonerations; DNA Evidence

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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 very few credible attempts at estimating 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 high 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 legal system as a whole by substantial parts of society.

As stated above though, while racial disparities in policing and sentencing have received a lot of attention from researchers, there exist few formal statistical analyses of racial disparities in wrongful conviction rates (the exceptions being Harmon (2001, 2004), Anwar, Bayer, and Hjalmarsson (2012), and Alesina and La Ferrara (2014), which we discuss in more detail below). The likely reason for this is that whether or not a given convicted defendant is guilty of the accused crime is often not observable with certainty. While it is undoubtedly true that the vast majority of those convicted for crimes in the United States are guilty of the crimes for which they have been convicted, there exist arguably credible estimates that a non-trivial number of innocent individuals are falsely convicted. For example, Gross et al. (2014) estimate that at least four percent of all individuals sentenced to death since 1973 were actually innocent.

The interest of this paper is to provide credible estimates of the relative difference in wrongful conviction rates across races for two types of crimes----sexual assault and murder. On the face of it these seem to be very difficult parameters to uncover because, as alluded to above, it is simply not possible to know innocence or guilt with certainty for a large fraction of those convicted. Indeed, while all convicts either must have admitted to the crime during plea bargaining or been found guilty beyond a reasonable doubt by a jury or judge, neither of these methods confirm guilt with certainly.[1]

However, there does exist one set of convicts for which we know guilt or innocence with near certainty---namely those who are exonerated due to new evidence of innocence and particularly those

[1] For example, evidence can be fabricated, exculpatory evidence withheld from the defendant, witnesses may be mistaken or perjure themselves, or innocent defendants may plead guilty in order to avoid the possibility of a harsher sentence should they be convicted at trial.

who are exonerated through DNA evidence. In these cases, the facts of the case could not support guilt without a DNA match, or the DNA implicated another individual of the crime. As we show below, if one assumes that the likelihood of exoneration for innocent white defendants is equal to or greater than the that for innocent black defendant convicted for a similar crime in the same year, then we can identify an upper bound of the ratio of the *wrongful conviction rate for whites relative to blacks* for that crime type by estimating the expected value of the ratio of the *white exoneration rate* relative to the *black exoneration rate* amongst individuals convicted for the same crime type in the same year. The importance of this is that while wrongful conviction rates by race cannot be observed, exoneration rates by race can be observed. Thus, we can use the ratio of exoneration rates across races to uncover information about the ratio of wrongful conviction rates across races.

We argue that our key assumption---i.e., that the likelihood of exoneration for an innocent white defendant is greater than or equal to the likelihood of exoneration for an innocent black defendant convicted for the same crime in the same year--- is quite credible for sexual assault cases and murder cases (by far the two types of cases mostly likely to be exonerated post-conviction). However, the greater the difference between the likelihood of exoneration for innocent whites relative to innocent blacks, the more our upper bound statistic will exceed the actual ratio of the wrongful conviction rate for whites relative to blacks. Therefore, we primarily focus on our estimates with respect to sexual assault cases where we only use exonerations due to DNA evidence. We argue that relative to other forms of exoneration and other crimes, the likelihood of a DNA exoneration amongst innocent defendants convicted for sexual assault in the same year is likely to be relatively close across races, making our estimated statistic from using such exonerations to be most informative regarding the actual ratio of the white to black wrongful conviction rate for sexual assault (though still likely an upper bound to this ratio).

Our results are quite dramatic when it comes to sexual assault. Over the last 25 years, our results suggest that the *rate of wrongful convictions amongst white defendants convicted for sexual assault is less than one-third the rate of wrongful convictions amongst black defendants convicted for sexual assault*. Or, in other words, blacks defendants convicted for sexual assault are over three times more likely to be innocent than white defendants convicted for sexual assault. These findings with respect to sexual assault strongly reject the null hypothesis that the wrongful conviction rate is equal across races, and these results are robust to using just DNA exonerations as well as all exonerations, over a variety of different subsamples, and across regions. While our results suggesting a large racial discrepancy in wrongful convictions for sexual assault are strong and robust, our results with respect to racial differences in the rate of wrongful convictions for murder are inconclusive.

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 these works have simply 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, these examples alone 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, as discussed in more depth below, the National Registry of Exonerations has documented over 1,600 exonerations in the past 25 years. Moreover, this number 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 simply 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%". However, the majority of surveyed individuals in both studies indicated a belief that wrongful convictions occurred less than 5 percent of the time.

While the criminal justice professionals surveyed in the above studies certainly have more information than those outside the criminal justice system, it is by no means clear how accurate even their perceptions are regarding the frequency of wrongful convictions. Given this, a few studies have tried more data driven approaches, and the results generally suggest a much higher rate of wrongful convictions. For example, 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. A second stream of literature that is particularly related to the analysis below attempts to use exoneration data to uncover information on wrongful conviction rates. For example, Risinger (2007) estimates the rate of wrongful convictions in capital rape-murder cases by dividing the number of DNA exonerations in capital rape-murder convictions occurring 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) again 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 to be at least 4.1 percent.

Why Do Wrongful Convictions Occur?

Wrongful convictions obviously occur because police, judges, and juries often only have imperfect information regarding any given defendant's actual guilt. [2] However, the likelihood of wrongful convictions can be exacerbated for a variety of reasons (Huff 2002; Huff, Rattner, and Sagarin 1986; Castelle and Loftus 2001), including police and/or prosecutorial misconduct (Boyer 2001; Joy 2006), coerced confessions (Kassin 1997; Leo and Ofshe 1998), unreliable informants (Zimmerman 2001), ineffective counsel (Radelet, Bedau, and Putnam 1992), and even political pressure. 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).

Arguably, however, the most common reason for a wrongful conviction is eyewitness error (Huff et al. 1996; Scheck et al. 2000), where an eyewitness to the crime identifies an innocent individual as the perpetrator with high confidence. Indeed, because of concerns about eyewitness identification error, the National Academy of Sciences recently delivered a wide-ranging report on the issue (National Research

[2] 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.

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 of a different race than the perpetrator, particularly in sexual assault cases (see Meissner and Brigham (2001) for a thorough review of this literature).

Race and Wrongful Convictions

As alluded to in the introduction, a variety of studies have looked at issues regarding racial bias in in the charging and sentencing process (e.g., Bushway and Piehl 2001; Everett and Wojtkiewicz 2002; Rehavi and Starr 2014; Mustard 2001; Ulmer, Light, and Kramer 2011; US Sentencing Commission 2012; Shermer and Johnson 2010; Raphael and Stoll 2013) 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).[3] However, 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 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) further extends this line of inquiry by looking at capital convictions, and finds the combination race of the defendant and victim in capital convictions is correlated with the eventual fate of the convicted defendant. While the results of the studies discussed above are consistent with a higher rate of wrongful convictions among blacks than whites, such studies are at best suggestive rather than conclusive.

As alluded to in the Introduction above, Alesina and La Ferrara (2014) take Harmon's (2004) approach one step further. They argue that if the court system was racially unbiased in its treatment of defendants, then while likelihood that a conviction is overturned on appeal may differ by race of the victim, any such difference such not differ by race of the defendant. However, they find that the likelihood that a black defendant's capital conviction is overturned on appeal is significantly higher when the victim is white than when the victim is black. By contrast, if anything, the likelihood that a white

[3] 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.

defendant's capital conviction is overturned on appeal is slightly lower when the victim is white than when the victim is black. This result appears to be fully driven by southern states.

This analysis below is complementary toward Alesina and La Ferrara's (2014) findings, but differs in several important ways. First, we look at the racial difference in wrongful conviction rates over all murder and sexual assault convictions, not just ones that lead to a death sentence. Second, while Alesina and La Ferrara's (2014) approach can test for answering whether black defendants are more likely to be wrongfully convicted than white defendants, it is limited in describing how large this bias is. In other words, it cannot very precisely answer the question "how much more likely are black defendants to be wrongfully convicted than white defendants?" We hope the approach we develop here is better able to answer such a question.

Another important study that provides a strong background and motivation for our work that follows is Anwar, Bayer, and Hjalmarsson (2012). In this study, the authors look at the relationship between race of defendant and the racial composition of the jury in conviction decision. They find strong evidence that black defendants are significantly more likely to be convicted when formed from an all-white jury pool than when there is even a single black member of the jury pool. While these results do not necessarily suggest that black defendants are more likely to be *wrongfully* convicted than white defendants, it does suggest that the evidence required for conviction may be quite sensitive to the race of the defendant.

Exonerations and DNA Evidence

There are a variety of ways wrongfully convicted defendants later have become exonerated. Sometimes exonerations arise due to witnesses recanting or because witnesses were later found to have perjured themselves, or 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 these issues were the direct cause of the determination of guilt and that their revelation must imply that the convicted defendant is actually not guilty. Clearly, to achieve an exoneration in one of these ways the defendant must be able to secure committed, high quality legal counsel.

Another avenue to exoneration, sometimes complementary to those discussed above, has been through DNA evidence. The first time such evidence was used to help exonerate a convicted felon in the United States was 1989. Over time, DNA testing has become cheaper, more accurate, and able to be performed on smaller and smaller tissue samples (Scheck and Neufeld 2001). 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. Indeed, in some cases testing a useable DNA sample can in and of itself exclude the possibility that individual committed a certain crime by excluding the possibility that DNA found at the crime scene was his.

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 sexual assault cases, testable samples still 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).

As we will discuss in more detail below, key to our analysis will be the assumption that the likelihood of exoneration for an innocent white individual is at least as high as the likelihood of exoneration for an innocent black individual. However, if this likelihood of exoneration for wrongfully convicted whites is substantially higher than it is for wrongfully convicted blacks, our estimation procedure may not be informative. Regretfully, it is impossible to examine these issues directly. While, on average, black Americans have less education and lower incomes than white Americans, which may both be correlated with the ability to find and retain high quality counsel, it is less clear that these racial differences hold with respect to individuals convicted for particular crimes. However, given the relatively low cost of DNA testing, and the potentially high exculpatory value of a finding favorable to an innocent defendant, particularly those convicted for sexual assault, we feel that the primary obstacle a wrongly convicted sexual assault defendant faces in appealing to DNA evidence is simply whether or not exculpatory DNA evidence exists. Arguably then, the existence of such evidence has little correlation with defendant race. Therefore, relative to other forms of exonerations, we think it plausible that the likelihood of an innocent defendant being exonerated by DNA evidence is quite similar across defendant races, particularly for sexual assault. As we will see below, this will be a key aspect of our analysis.

III – Empirically Uncovering Racial Differences in the Rate of Wrongful Convictions

We are interested in estimating the ratio of the rate of wrongful convictions for white defendants (π_W) relative to the analogous rate for black defendants (π_B), or π_W/π_B, for a given type of crime *c*. The obvious hurdle is that π_W and π_B cannot be directly observed to calculate this ratio of interest. However, suppose we can observe the number of defendants of each race *r* convicted for crime *c* in year *t* who have been exonerated (denoted $EXON_{r,t}$), as well as the total number of individuals convicted for crime c in year t from each race (denoted $N_{r,t}$ for defendants of race r convicted in year t). The question of interest is under what assumptions can such information be used to recover information about the magnitude of π_W/π_B? For ease of reference, the following discussion presumes we are only talking about individuals convicted for one specific type of crime c (e.g., sexual assault).

Consider the following assumptions. Suppose that for any given *innocent* defendant of race r convicted in a given year t, the ex-ante likelihood that he is exonerated between 1986 and 2006 (the years for which we have data) is determined by a simple *independent* Bernoulli trial with parameter $p_{r,t}$. In words, assume that for any given innocent defendant of race r convicted in year t, the likelihood that exculpatory evidence exists and is brought before the court and found to exonerate the defendant between 1986 and 2006 is equal to $p_{r.t}$, regardless of what happened to other innocent defendants convicted year t. This implicitly assumes that to the extent there is either congestion in courts or innovations in the exoneration process over time (e.g., advances in DNA testing), such issues apply equally to all innocent individuals of the same race convicted in the same year and therefore are captured in $p_{r,t}$.[4] In other words, $p_{r,t}$ can differ across cohorts convicted in different years, but is the same for all innocent defendants of the same race in the same conviction year cohort. Moreover, $p_{r,t}$ is allowed to differ across races within the same conviction cohort, meaning innocent whites may have a different likelihood of exoneration than innocent blacks in the same conviction cohort. Finally, let us assume that the likelihood that a guilty individual of either race is exonerated is zero.[5]

Given the notation above, the number of *wrongfully* convicted individuals from race r convicted in period t will simply be $\pi_r N_{r,t}$. Moreover, given assumptions in the previous paragraph, the number of exonerations of defendants of race r convicted in any period t will be an independent random variable drawn from a simple binomial distribution of population size $\pi_r N_{r,t}$ and parameter $p_{r,t}$. Therefore, the expected number of individuals from race r who were convicted in year t that are exonerated between 1986 and 2006 will equal

$$(1) \qquad \mathrm{E}[\mathrm{EXON}_{r,t}] = p_{r,t}(\pi_r \mathrm{N}_{r,t}).$$

As can be directly seen above, the expected number of exonerations among of individuals of race r convicted in year t is the product of the total number convicted ($N_{r,t}$), the fraction wrongfully convicted (π_r), and the likelihood of each wrongfully convicted individual to become exonerated ($p_{r,t}$). While the

[4] Note, this also recognizes that exonerations take time and the time between conviction and time T (i.e., the last year of our data) differs across conviction cohorts.

[5] While there certainly are guilty individuals whose sentences are vacated due to legal issues, the "exonerations" we refer to here include only those cases where "a person who has been convicted of a crime is officially cleared of the crime based on new evidence of innocence" (National Registry of Exonerations).

number of exonerations ($EXON_{r,t}$) and the number of convictions ($N_{r,t}$) for each cohort by race are potentially observable, the wrongful conviction rate (π_r) and the likelihood of exoneration conditional on being wrongfully convicted ($p_{r,t}$) are not. So the question is how to gain information about the magnitude of π_W relative to π_B given we cannot separately observe them from $p_{W,t}$ and $p_{B,t}$. This leads to our key assumption.

Key Assumption: The likelihood of exoneration *conditional on being wrongfully convicted* is at least as high for white defendants as it is for black defendants convicted in the same year (for the same crime), or $p_{W,t} \geq p_{B,t}$.

As we show next, this assumption will allow us to bound π_W/π_B using only data on exonerations and convictions. Specifically, let us define the statistic θ to be the ratio of the exoneration rate for whites convicted in year t relative to the exoneration rate for blacks convicted in year t, or

$$\theta \equiv \frac{\mathrm{EXONRT}_{W,t}}{\mathrm{EXONRT}_{B,t}}, \tag{2}$$

which is equivalent to

$$\theta = \frac{EXON_{W,t}/N_{W,t}}{EXON_{B,t}/N_{B,t}},$$

which in turn can be re-written

$$\theta = \frac{EXON_{W,t}}{EXON_{B,t}} \times \frac{N_{B,t}}{N_{W,t}}.$$

Now consider the expected value of θ, or

$$E[\theta] = E\left[\frac{EXON_{W,t}}{EXON_{B,t}} \times \frac{N_{B,t}}{N_{W,t}}\right]. \tag{3}$$

Note that the ratio of black to white convictions in year t, $N_{B,t}/N_{W,t}$ is determined prior to the random process through which wrongfully convicted defendants get exonerated, and we assume that the wrongful conviction rate π_r and likelihood of exoneration given innocence for any given cohort $p_{r,t}$ are independent of the number of convictions in a given cohort $N_{r,t}$. Therefore, $N_{B,t}/N_{W,t}$ can just be treated as a constant in equation (3), meaning

$$E[\theta] = E\left[\frac{EXON_{W,t}}{EXON_{B,t}}\right] \times \frac{N_{B,t}}{N_{W,t}}.$$

Further note that 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 $E[X/Y] \geq E[X]/E[Y]$. Therefore, given the assumption that whether or not each innocent individual convicted in year t is exonerated is the outcome of an independent Bernoulli trial, $EXON_{B,t}$ and $EXON_{W,t}$ are independent random variables coming from binomial distributions over different population sizes, Jensen's inequality will also imply that

$$E[\theta] \geq \frac{E\left[EXON_{W,t}\right]}{E\left[EXON_{B,t}\right]} \times \frac{N_{B,t}}{N_{W,t}}.$$

Given equation (1) we know the above equation will then also imply

$$E[\theta] \geq \frac{p_{W,t}\pi_W N_{W,t}}{p_{B,t}\pi_B N_{B,t}} \times \frac{N_{B,t}}{N_{W,t}},$$

or equivalently

$$E[\theta] \geq \frac{p_{W,t}\pi_W}{p_{B,t}\pi_B}.$$

Given our key assumption that $p_{W,t} \geq p_{B,t}$ it will then also be true that

$$E[\theta] \geq \frac{p_{W,t}\pi_W}{p_{B,t}\pi_B} \geq \frac{p_{W,t}\pi_W}{p_{W,t}\pi_B}.$$

or

$$E[\theta] \geq \frac{p_{W,t}\pi_W}{p_{B,t}\pi_B} \geq \frac{\pi_W}{\pi_B}.$$

In words, under the assumptions laid out above, the expected value of the ratio of the exoneration rate for whites relative to the exoneration rate for blacks convicted in the same year for the same crime (i.e., θ) will provide an upper bound on the ratio of the white wrongful conviction rate to the black wrongful conviction rate for that crime (i.e., π_W/π_B). However, the distance from this bound statistic to the true ratio of white to black wrongful conviction rates will be greater the greater $p_{W,t}$ is relative to $p_{B,t}$.

In summary, by using the potentially observable data regarding exonerations and convictions by race by year of conviction for a given crime, we can estimate an upper bound on the 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 is a project facilitated through the University of Michigan Law School, 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). 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.

As stated by the website for the National Registry of Exonerations, for the purposes of this data set, an *exoneration* is defined as being a case where a person who has been convicted of a crime is officially cleared based on new evidence of *innocence*. In other words, cases where a conviction is vacated simply due to legal errors are not included as exonerations in this 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."

The Registry of Exonerations has documented well over 1,600 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.

The Registry of Exonerations shows that there has been at least one exoneration in each state since 1989 (see Table A1 in Appendix). The mean number of exonerations per state since 1989 is thirty-two, with a median of fifteen. The set of four states with the most exonerations since 1989 include Illinois, California, New York, and Texas, which obviously also are some of the biggest states. To adjust for the population of the state, we can calculate exonerations per million residents (using the state population in 2000). Using this measure, the mean number of exonerations since 1989 is five per million residents. As can be seen in Table A2 in the Appendix, the set of four states with the largest number of exonerations since 1989 per million residents now includes Louisiana, but continues to include Texas, New York, and Illinois. Moreover, Washington D.C. has the highest number of exonerations since 1989 per million residents at 26 (but this includes both convictions that occurred in the city of Washington D.C. as well as federal convictions that occurred in the Washington D.C. Federal District Court).

Table 1 shows the number of exonerations and percent of all exonerations by crime type. As can be seen, by far the most exonerations have been for murder (including manslaughter), followed by sexual assault. As discussed in Gross et al. (2005), the Child Sex Abuse exonerations almost all stem from a wave of false accusations made in the 1990s. Figure 1 shows the number of exonerations by year. As can be seen, there has been a relatively steady climb in exonerations since the beginning of the data collection in 1989. Figure 2 shows this information in a slightly different way, namely the number of exonerations by conviction year cohort. As can be seen, this graph is hump shaped, with few exonerations of individuals convicted prior to the early 1980s, a relatively large number of exonerations of individuals convicted in the late 1980s and 1990s, with a fewer number of exonerations of those convicted in the 2000s. This likely reflects two issues. First, DNA evidence did not start to become used until the early 1980s and has become increasingly more widespread and sophisticated since. Therefore, many innocent individuals convicted prior to the early 1980s were far less likely to have DNA testing technology available to help their case. Second, exonerations take time. Indeed, the mean time from conviction to exoneration is 10.5 years. Interestingly, the mean time between conviction and exoneration is even longer for DNA exonerations at almost 16 years. Therefore, relative to those convicted in the 1980s, a higher proportion of individuals wrongfully convicted in the 2000s likely simply haven't had time for exculpatory evidence to make it into the court.

In regards to DNA exonerations, Table 2 shows that overall, 24 percent of exonerations are due to DNA evidence, with 407 DNA exonerations in the data. However, this rate varies dramatically by crime type. While 69 percent of sexual assault exonerations are based on DNA evidence, only 23 percent of murder exonerations are based on DNA evidence. Moreover, in raw numbers, there are very few DNA exonerations for other types of crime. In terms of race and DNA, again it depends on the type of crime. Table 3 shows that overall, DNA evidence was a contributing factor for exoneration for 32 percent of black exonerees, but only 22 percent of white exonerees. However, as the lower to rows show, this discrepancy depends on type of crime. For sexual assault exonerations, DNA evidence was a contributing factor in exoneration for over 75 percent of black exonerees, but less than 60 percent of white exonerees. By contrast, DNA evidence was a contributing factor for exoneration for roughly a quarter of both black and white defendants exonerated for murder. What these results make clear is that DNA evidence is a contributing factor for exoneration for the vast majority of sexual assault exonerees of both races, but particularly among black exonerees. This most certainly does not imply that innocent black sexual assault convicts are more likely than innocent white sexual assault convicts to be exonerated due to DNA evidence (which would violate the key identification assumption alluded to above). Rather, it simply shows that innocent white defendants convicted for sexual assault are more frequently exonerated by means other than DNA evidence than are innocent black defendants convicted for sexual assault, which is certainly consistent with the key identifying assumption discussed in Section III.

The second data source we employ is the National Judicial Reporting Program, which we use to compute the ratio black defendants to white defendants convicted for sexual assault and murder each year. This data 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. The National

Judicial Reporting Program collects convictions data from state courts and prosecutors in one hundred United States counties in a given year. The sampling design is such that the data when weighted should be nationally representative of all convictions for that year. The variables contained in this data set include crime type, age, sex, and race of each convicted felon.

There are two drawbacks to this data for this analysis. First, this data is only collected in even numbered years between 1986 and 2006. However, as we discuss in more detail in the next section, the fact that we have exoneration data for individuals convicted each year from 1989 – 2006 but conviction data only every other year from 1986 – 2006 will not really affect our results other than the precision of our estimates. The second issue with the National Judicial Reporting Program dataset is that race data is missing for about 30 percent of the observations. Moreover, data on Hispanic ethnicity of the defendant is missing for over 60 percent of the observations, and race or Hispanic ethnicity is missing for over 70 percent of the observations. Given these later two issues, we do not attempt to estimate the ratio of wrongful convictions for Hispanics relative to non-Hispanics, and both our categories "black" and "white" include Hispanics.

With regards to missing data on race, it seems unlikely to have a dramatic impact on our results as our estimation procedure simply requires the ratio of blacks convicted for a given crime in a given year relative whites convicted for the same crime in the same year. Therefore, as long as one assumes the racial composition of those defendants missing race data is similar to the racial composition of those with valid data regarding race, our results will be valid. Is such an assumption reasonable? Looking at Table 4 we see very little difference in four key characteristics between those defendants with missing race data and those with valid race data. The age and gender composition of these two groups are very close, and the fraction convicted for sexual assault and murder (the crimes we will analyze) are almost identical across these two groups. Moreover, despite these missing data, this is the data the Bureau of Justice Statistics (part of the U.S. Department of Justice) uses to compute the racial make-up of those convicted for felonies in its *Felony Sentences in State Courts* report series.

This all being said, in our preferred specifications we limit the sample (including exonerations) to states for which at least 50 percent of the observations in the National Judicial Reporting Program data have valid data on race (34 states). However, we also look at how the results change if we use all states for which about 25 percent of the observations have race data (43 states), as well as all states.

Finally, given it is difficult to obtain data on the race of those convicted for felonies in Federal courts before 1994, and the fact that there are only 4 exonerations of individuals convicted for sexual assault happened in a Federal Court and only 7 exonerations of individuals convicted for murder in a Federal Court, we limit our analysis to only convictions (and associated exonerations) that occur in state courts.

V - Estimation

As discussed above, our goal is to estimate the expected value, or mean, of the ratio of the white exoneration rate to the black exoneration rate among individuals convicted in the same year for the same crime. As discussed above, this will provide an upper bound on the rate of wrongful convictions of whites relative to blacks for that crime. As shown above, this is equivalent to estimating

$$E[\theta] = E\left[\frac{EXON_{W,t}}{EXON_{B,t}} \times \frac{N_{B,t}}{N_{W,t}}\right]. \tag{4}$$

As discussed above, if we measured $N_{B,t}$ and $N_{W,t}$ directly each year, their ratio could just be treated as a constant, meaning

$$E[\theta] = E\left[\frac{EXON_{W,t}}{EXON_{B,t}}\right] \times \frac{N_{B,t}}{N_{W,t}}.$$

However, the National Judicial Reporting Program data only gives us *estimates* of $N_{B,t}$ and $N_{W,t}$ (and only for even years). This means $N_{B,t}/N_{W,t}$ is also a random variable each year and cannot be treated like a constant for the purposes of estimation. However, it seems quite reasonable to assume that the randomness inherent in $N_{B,t}/N_{W,t}$ for each conviction year t due to sampling error is independent of the randomness inherent in the realization of the ratio of the number of white exonerations to black exonerations coming from the underlying set of wrongfully convicted defendants from conviction year t ($EXON_{W,t}/EXON_{B,t}$). Therefore, θ is simply the product of two independent random variables, meaning equation (4) can be re-written as

$$E[\theta] = E\left[\frac{EXON_{W,t}}{EXON_{B,t}} \times \frac{N_{B,t}}{N_{W,t}}\right] = E\left[\frac{EXON_{W,t}}{EXON_{B,t}}\right] \times E\left[\frac{N_{B,t}}{N_{W,t}}\right]. \tag{5}$$

Given equation (5) and using the analogy principle, our basic estimation strategy will be to calculate the sample mean of the ratio of white to black exonerations for a given crime over the 21 conviction year cohorts (1986-2006) times the sample mean of the ratio of black convictions to white convictions for that crime over the 11 conviction year cohorts for which we have data (1986-2006 every other year), or

$$\bar{\theta} = \left(\sum_{t=1986}^{2006} \left(\frac{EXON_{W,t}}{EXON_{B,t}}\right)/21\right) \times \left(\sum_{t=1986}^{2006} \left(\frac{N_{B,t}}{N_{W,t}}\right)/11\right). \tag{6}$$

As can be seen in the above equation, another issue arises if there are no exonerations of black defendants convicted for a given crime in a given conviction year cohort, as this would lead to a zero in the denominator of the first component. To account for this, in years where *either* $EXON_{B,t}$ or $EXON_{W,t}$

equals zero, we use $\left(\frac{EXON_{W,t}+1}{EXON_{B,t}+1}\right)$ in the first component of equation (6) above. Intuitively, this means that in conviction cohorts where there are no exonerations for defendants of either race, this ratio will equal one---implying an equal number of exonerations across races for that year (which is actually true). On the other hand, in conviction cohorts where, for example, $EXON_{W,t} = 1$ but $EXON_{B,t} = 0$, the ratio $\left(\frac{EXON_{W,t}+1}{EXON_{B,t}+1}\right)$ for that cohort would equal 2/1---implying that there were twice as many white exonerations as black exonerations in that cohort. This is obviously not quite correct, but we hope it is a reasonable approximation. This is certainly not innocuous though. For example, in 1988 and 1993, there are five black sexual assault convicts exonerated through DNA evidence but only two white sexual assault convicts. So, in these years, the ratio in first part of equation (6) will equal 0.4. Compare this to a year such as 1995 where one black sexual assault convict was exonerated through DNA evidence but no white sexual assault convicts were. Given the adjustment procedure described above, the ratio in the first part of equation (6) for this example will be 0.5---a number pretty close to 0.4.

While we think this is a reasonable way to adjust for zeros, it is a concern that this adjustment might have an impact on our results. As can be seen in Figures 3a and 3b though, there is at least one DNA exoneration for murder and sexual assault among each conviction cohort from 1986 – 2000. However, among the 2001-2006 conviction cohorts combined, there is only one DNA exoneration for sexual assault. A similar though not as dramatic drop off in DNA exonerations arises for those convicted for murder post-2000. So, the procedure described in the above paragraph could substantially impact our results when we include the years 2001 and later. Therefore, we also estimate our statistics of interest using only the 1986 – 2000 conviction cohorts to ensure our results are not driven by this adjustment procedure. Moreover, as we discuss below, in order to assess the statistical significance of our results, we use a bootstrap procedure that uses the same correction procedure for zeros as described above, and therefore should account for any systematic biases that arise from this procedure.

Calculating the standard error for $\bar{\theta}$ is not trivial, as we have to take into account both the underlying random variation inherent in the realized ratio of exonerations for each conviction cohort ($EXON_{W,t}/EXON_{B,t}$), as well as the sampling variation associated with the ratio of convictions each year ($N_{B,t}/N_{W,t}$). We discuss this issue in more detail in the Appendix, but we handle this in two ways. First, we compute analytic standard errors that account for both sources of variation (see Appendix for details). Second, given the fact that we have relatively few cohort observations (21 cohorts for exoneration data, 11 cohorts for conviction data) and that only an extremely small number of convictions end up being exonerated (including zero in some years), we also bootstrap methods (as alluded to above) to test our statistic obtained from estimating equation (6) against as the *null* hypothesis that the white wrongful conviction rate *is equal* to the black wrongful conviction rate.

In particular, we use a bootstrap procedure to compute the p-values of our estimated statistics under the null hypothesis that the true rate of wrongful convictions is equal across races. Specifically, for each bootstrap draw, we pull a random sample of convictions from each conviction cohort with replacement and then randomly assign whether each convict in the bootstrap sample is "exonerated," where the likelihood that any given convict from a given conviction cohort in the bootstrap sample is "exonerated" is forced to be equal across races.[6] Based on this bootstrap sample, we then compute the statistic described above in equation (6). We do this procedure for one thousand different bootstrap samples. In words, one can interpret the p-values shown in the tables below as indicating the likelihood of observing a value of our estimated statistic as low as what we find if the wrongful conviction rate (and likelihood of exoneration conditional on wrongful conviction) is the same for whites as it is for blacks. Note, we think these p-values are conservative in the sense that they will overstate the statistical likelihood of the null if the likelihood of exoneration for a wrongfully convicted white defendant is substantially larger than it is for a wrongfully convicted black defendant.

As one final note of import with respect to interpreting our estimated statistics, recall that our statistic to be estimated is an upper bound measure, namely

$$E[\theta] \geq \frac{p_{W,t}}{p_{B,t}} \frac{\pi_W}{\pi_B} \geq \frac{\pi_W}{\pi_B}.$$

This means that this statistic is simply not informative if it is statistically equal to or greater than one, as even if the wrongful conviction rate for whites is lower than the wrongful conviction rate for blacks (i.e., $\pi_W/\pi_B < 1$), our estimated value may be statistically equal to or greater than one if the likelihood of exoneration given wrongful conviction is much greater for whites than blacks (i.e., $p_{W,t} / p_{B,t} > 1$), and therefore not reject the null hypothesis that $\pi_W/\pi_B \geq 1$. In other words, it may be the case that our estimated statistic is simply uninformative. This of course limits the power of our test since we cannot interpret a null finding.

Similarly, while we can test whether the wrongful conviction rate for whites is lower than it is for blacks within in states limited to a specific region (i.e., Southern states, Midwestern states, Northeastern states, Western states) using the procedure above, we cannot test whether the ratio of white to black wrongful conviction rates statistically differs across regions for the reasons discussed in the previous paragraph. Namely, our estimated statistic can differ across two regions either because the ratio of wrongful conviction rates across races (π_W/π_B) differs across the two regions, or because the racial difference in the likelihood of exoneration given innocence ($p_{w,t}/p_{B,t}$) differs across the two regions.

[6] Specifically, in our bootstrap method, the likelihood of exoneration for each member of each conviction cohort (regardless of race) is determined by the realization of a single random draw from a uniform distribution bounded by the minimum and maximum exoneration rate across all years of data.

VI - Results

Recall from above that our key identifying assumption is that the likelihood of exoneration for an innocent white defendant is at least as high as the likelihood of exoneration for an innocent black defendant convicted for the same crime in the same year. Under this assumption, our estimate of the expected value of our statistic θ as described by equation (6) will give us an upper bound on the underlying parameter of interest, which is the ratio of the rate of wrongful convictions among white defendants relative to black defendants (π_W/π_B). Moreover, the closer are the likelihoods of exoneration among the innocents across races, the closer the expected value of our estimated statistic will be to π_W/π_B, while the more the likelihood of exoneration for an innocent white defendant exceeds the likelihood of exoneration for an innocent black defendant, the more our estimated statistic will overstate the true value of π_W/π_B.

As we discuss above, we think the likelihood of exoneration by DNA evidence amongst innocent individuals convicted for sexual assault is likely to be most similar across races, at least relative to other crimes and other forms of exoneration. Therefore, relative to other forms of crime and more inclusive definitions of exoneration, we think our estimated statistic will be most informative regarding the ratio of the rate of wrongful convictions among white defendants relative to black defendants convicted for sexual assaults, especially when we limit the definition of exoneration to only include exonerations arising from DNA evidence.

Estimating the expected value of θ for sexual assaults via equation (6) using only DNA exonerations, and only using data from states in which at least 50 percent of the observations in the conviction data had valid data on race, gives us a value of 0.31 (s.e. 0.05), which corresponds to a bootstrapped p-value of the null hypothesis that the wrongful conviction rate is equal across races of less than one in a thousand. *This implies that the rate of wrongful convictions among whites convicted for sexual assaults is less than one-third the rate of wrongful convictions among blacks convicted for sexual assaults*. Moreover, the p-value implies that the likelihood that such a value for this statistic would arise if the likelihoods of wrongful conviction for sexual assault were actually equal across races is exceedingly rare.

To consider the robustness of this result, Table 5 shows our estimates of ratio of wrongful conviction rates for sexual assault across races under a variety of different alternative specifications. The top row in Column (1) in Table 5 shows the estimate discussed in the previous paragraph, namely the estimate of equation (6) when using only DNA exonerations and only data from states where we had race data for more than 50 percent of the conviction sample (the standard error of this value is in parentheses below the estimate and the bootstrapped p-value of the null is in italics below the standard error). One concern is that states with more missing race data are systematically different than other states. Moving across the top row of columns in Table 5 alleviates this concern as we find little difference in our estimates when we expand our sample to include states with more missing race data with respect to convictions.

The second row of Table 5 shows results analogous to the top row but uses all types of exonerations rather than just DNA exonerations. As can be seen, the estimated statistic is now a bit larger in each case, ranging from 0.49 to 0.61. As discussed above, one reason for this might be that, relative to DNA exonerations, the likelihood that an innocent white individual convicted for sexual assault is exonerated by non-DNA evidence is substantially larger than it is for an innocent black individual convicted for sexual assault, which leads to more upward bias in our estimated statistic relative to the true ratio of wrongful conviction rates of whites relative to blacks. However, while bigger, the associated p-values show that we can still reject the null hypothesis that the white wrongful conviction rate is equal to or greater than it is for blacks at the 1 percent level or higher in all cases.

The third row of Table 5 presents our estimates by comparing all non-blacks (i.e., not just Caucasians, but also Asians, Native Americans, and Pacific Islanders) to blacks. As can be seen, these results are almost identical to those in the top row comparing whites to blacks.

Finally, as discussed above, there is only one DNA exoneration among all of the individuals convicted for sexual assault from 2001-2006 combined, meaning our correction procedure for a zero in the denominator may be having more of an impact on our results when these years are included. Hence, it may be more appropriate to estimate our statistic using only data from the 1986 – 2000 cohorts for which this correction procedure does not need to be employed. The fourth row of Table 5 shows the results when the sample is limited in this way. As can be seen, our estimated statistic is even lower (ranging 0.25 to 0.32) using this shorter time frame, and again the bootstrapped p-values show that the null hypothesis that the likelihood of wrongful conviction is equal across races is strongly rejected in each subsample.[7]

An obvious concern with respect to these results is the small sample size. Effectively, we only have 21 observations (i.e., yearly observations from 1986-2006). Given this limited number of observations, we certainly want to exclude the possibility that one particular year is driving our results. While the bootstrapped p-values help in minimizing this concern, we also assess this issue in another way. In particular, we re-estimate the parameters in Table 5, but dropping one year of data each time. We then can assess how sensitive our estimates are to the inclusion any particular year by examining how much variation arises in our estimated parameter when each particular year is sequentially excluded from the estimation procedure. Table 6 shows the results of this exercise for states where we have race data for

[7] One might also be concerned that since our exoneration data does not start until 1989, we might be missing several exonerations of individuals convicted in 1986 and 1987 and that this might be affecting our results. Given most exonerations take far more than one or two years this is unlikely to affect our results. Nevertheless when we limit our sample to the 1988-2006 cohort the results are essentially identical to the top row of Table 5.

more than 50 percent of convictions.[8] The first column of numbers simply shows our results from Column (1) of Table 5 when all years of data are used in the estimation procedure. The second, third, and fourth columns of numbers in Table 6 show the standard deviation, the minimum, and the maximum estimate in the distribution of estimates that arise when we re-estimate our statistic on a subsample of years excluding one year each time. As can be seen, our estimated results are not very sensitive to excluding any particular year of data, suggesting that it is not any particular year driving our results.

Table 7 looks again at sexual assault convictions, but does separate estimates for each region. For each region, the results are shown for when exonerations are limited to DNA exonerations only, as well as all exonerations, and when the sample is limited to states with greater than 50 percent of convictions having race data, states with at least 25 percent of convictions having race data, and all states. As can be seen, our estimated statistic is below one in each region in each subsample and the associated bootstrapped p-values are generally low enough to reject the null hypothesis that the wrongful conviction rate for whites is greater than or equal to the wrongful conviction rate for blacks at standard significance levels in each region (except for the "all states" subsample in the West).

One thing that is noticeable in Table 7 is that our estimated statistics are smaller in Midwestern and Western states than they are in the Southern or Northeastern states. However, such differences across regions may actually not be particularly informative. As discussed in the final paragraph of Section III, these results do *not* imply that the ratio of the white wrongful conviction rate to the black wrongful conviction rate is smaller in Midwestern and Western states than it is in Southern and Northeastern states. These different estimated values of our statistic across regions could either arise because the ratio of wrongful conviction rates across races differs across regions, or arise because the likelihood of exoneration for innocent whites relative to innocent blacks differs across regions. Our procedure cannot separately identify these two explanations.[9]

We can now turn to our results with respect to wrongful convictions for murder. If we use only DNA exonerations and only states where we have race data for at least 50 percent of the convictions, our estimated statistic from equation (6) equals 1.80 (s.e. 0.33). Obviously, given this estimate, we cannot reject the null hypothesis that the wrongful conviction rate for whites is equal to or greater than it is for blacks when it comes to murder (as can be seen by the p-value of 0.638). However, because this statistic simply provides an upper bound on the ratio of the wrongful conviction rate for whites relative to blacks

[8] Results are essentially the same when we include states were we have race data for over 25 percent of convictions, as well as all states. Results available upon request.

[9] The fact that our estimated statistics are well below zero in the West, but the p-values of these statistics are actually higher in the West than in other regions seems to be due to the fact that there are more years with zero exonerations in the West than in other regions, meaning our correction procedure for zeros in the denominator is being employed more in the West, which is also captured by our bootstrap procedure, essentially revealing our estimation procedure has less power in the West.

for murder, such a value is inconclusive. Again, the fact that it is not statistically less than one could either be because the wrongful conviction rate for murder is not lower for blacks than whites, or be due to the likelihood of exoneration being much higher for whites wrongfully convicted for murder than blacks wrongfully convicted for murder. Table 8 shows that the results for murder remain inconclusive across a variety of different specifications (e.g., using more states than just those with greater than 50 percent of convictions having race data, all exonerations versus only DNA exonerations, etc.).

Table 9 does the sensitivity check analogous to that done in Table 6, where we re-estimate our statistic on a subsample of the years excluding one year each time. Again, we only show the results for states for which we have race data for over 50 percent of convictions, but the results are similar if we include other states as well. As can be seen, our the variation in our estimates when we drop a given year are still not very high, again suggesting our results are not being overly influenced by any one particular year.

Not surprisingly, Table 10 shows that the results with respect to murder generally remain inconclusive when separated out by region. In Southern states, Northeastern states, and Midwestern states, the value of our estimated statistic is well above one, and in no region can we robustly reject the null hypothesis that the wrongful conviction rate is equal across races. In words, our results provide no evidence that the wrongful conviction rate for murder is any lower for whites than it is for blacks. Though again, it must be noted that our results also do not rule out this possibility since our estimated statistic simply provides an upper bound on the ratio of the white wrongful conviction rate to the black wrongful conviction rate.

VII - Conclusions

This paper estimates a ratio statistic that estimates a bound on the relative difference in the frequency of wrongful convictions across races. While our estimates are generally inconclusive with respect to murder, they are quite strong with respect to sexual assault. Indeed, our results suggest that the rate of wrongful convictions for sexual assault among black Americans is a least three times greater than it is for white Americans. Even this is a lower bound. To the extent to which the likelihood of DNA exoneration for innocent white convicts exceeds the likelihood of DNA exoneration for innocent black convicts, the relative rate of wrongful convictions among blacks convicted for sexual assault relative to whites must be even higher than our estimate discussed above.

We think these results are quite profound, as they directly imply that over the last two decades the American legal system has been 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 crimes they did not commit (particularly when it comes to sexual assault). To the extent to which these wrongfully convicted individuals are being convicted and incarcerated in lieu of the actual perpetrators of the same race, then these results also may suggest that there are a disproportionate number of black rapists failing to be punished for their crimes.[10] The fact that both of these failures of the justice system are disproportionately falling on the black community can no doubt lessen trust in the legitimacy of the American justice system in black communities.

How to repair this bias in the judicial system is not obvious. However, as alluded to 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. This is most prominently a concern with respect to sexual assault cases, for which our evidence of racial differences in wrongful conviction rates is the strongest. Indeed, in 80 percent of the cases in our data in which a black individual was found to be wrongfully convicted for sexual assault, witness identification was partly responsible for the conviction. The analogous rate for white individuals exonerated for sexual assault is only 57 percent. 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, seems to be an important first step in mitigating the apparent racial imbalance in wrongful conviction rates.

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

Appendix

Recall that our basic statistic we aim to estimate is

$$E[\theta] = E\left[\frac{EXON_{W,t}}{EXON_{B,t}} \times \frac{N_{B,t}}{N_{W,t}}\right],$$

or if we let A = ($EXON_{W,t}$)/($EXON_{B,t}$) and B = $N_{B,t}/N_{W,t}$, E[θ] = E[AB]. Under the assumption that the sources of variation for A and B are independent, then θ is just the product of two independent random variables. Therefore, Var(θ) = Var(AB) = E[A^2B^2] – E[AB]^2 = Var(A)E[B]^2 + E[A]^{2}Var(B) + Var(A)Var(B). Given this formula, $se(\theta) = \sqrt{\frac{\text{Var(A)E[B]2 + E[A]2Var(B) + Var(A)Var(B))}}{n}}$, where n is the number of observations (i.e., conviction cohorts for which we observe data).

References

Alesina, Alberto and Eliana La Ferrara. (2014). "A Test of Racial Bias in Capital Sentencing." American Economic Review 104(11): 3397-3433.

Alexander, Michelle. (2010). The New Jim Crow: Mass Incarceration in the Age of Colorblindness. New York, NY: The New Press.

Anwar, Shamena, Patrick Bayer, and Randi Hjalmarsson. (2012). "The Impact of Jury Race in Criminal Trials." The Quarterly Journal of Economics 127(2): 1017-55.

Anwar, Shamena and Hanming Fang. (2006). "An Alternative Test of Racial Prejudice in Motor Vehicle Searches: Theory and Evidence." American Economic Review 96(1): 127-151.

Antonovics, Kate and Brian Knight. (2009). "A New Look at Racial Profiling: Evidence from the Boston Police Department." The Review of Economics and Statistics 91(1): 163-177.

Barlow, A. (1999). "The Wrong Man." The Atlantic Monthly 284: 66-91.

Bedau, Hugo and Michael Radelet. (1987). "Miscarriages of Justice in Potentially Capital Cases." Stanford Law Review 40: 21-179.

Bjerk, David. (2007) "Guilt Shall Not Escape or Innocence Suffer: The Limits of Plea Bargaining When Defendant Guilt is Uncertain," American Law and Economics Review 9(2):305-329.

Borchard, E.M. (1932) Convicting the Innocent: Sixty-Five Factual Errors of Criminal Justice. Garden City NY: Doubleday.

Boyer, Peter. (2001). "Bad Cops." The New Yorker, May 21 2001.

Brandon, R. and C. Davies. (1973). Wrong Imprisonment: Mistaken Convictions and Their Consequences. London: Allen & Unwin.

Bushway, Shawn D. and Anne M. Piehl. (2001). "Judging Judicial Discretion: Legal Factors and Racial Discrimination in Sentencing." Law and Society Review 35(4): 733-764.

Donohue, John J and Steven D. Levitt. (2001). “The Impact of Race on Policing and Arrests.” Journal of Law and Economics 44: 367-394.

Castelle, George and Elizabeth Loftus. (2001). “Misinformation and Wrongful Convictions” In Saundra Westervelt and John Humphrey (Eds.), Wrongfully Convicted: Perspectives on Failed Criminal Justice, Piscataway NJ: Rutgers University Press, 17-35.

Christianson, S. (2004). Innocent: Inside Wrongful Conviction Cases. New York: New York University Press.

Cooper, C., S. Cooper, and S. Reese. (1995). Mockery of Justice: True Story of the Same Shepard Murder Case. Boston: Northeastern University Press.

Curry, Phil and Tilman Klumpp. (2009). “Crime, Punishment, and Prejudice.” Journal of Public Economics 93: 73-84.

Everett, Ronald and Roger Wojtkiewicz. (2002). "Difference, Disparity, and Race/Ethnic Bias in Federal Sentencing." Journal of Quantitative Criminology 18(2): 189-211.

Friedman, Ezra, and Abraham Wickelgren. (2006). “Bayesian Jurors and the Limits to Deterrence.” Journal of Law, Economics and Organization 22:70-86.

Frisbie, T., and B. Garnett. (1998). Victims of Justice. New York: Avon.

Gelman, Andrew, Jeffrey Fagan, and Alex Kiss. (2007). “An Analysis of the New York City Police Department’s ‘Stop-and-Frisk’ Policy in the Context of Claims of Racial Bias.” Journal of the American Statistical Association 102(479): 813-823.

Grogger, Jeffrey and Greg Ridgeway. (2006). “Testing for Racial Profiling in Traffic Stops from Behind a Veil of Darkness.” Journal of the American Statistical Association 101(475): 878-887.

Gross, Ronald and Barbara O’Brien. (2008). “Frequency and Predictors of False Conviction: Why We Know So Little, and New Data on Capital Cases.” Journal of Empirical Legal Studies 5(4): 927-962.

Gross, Ronald, Barbara O'Brien, Chen Hu, and Edward Kennedy. (2014). "Rate of False Conviction of Criminal Defendants Who Are Sentenced to Death." Proceedings of the National Academy of Sciences 111(20): 7230-7235.

Grossman, Gene and Michael Katz. (1983). "Plea Bargaining and Social Welfare." American Economic Review 73: 749-57.

Harmon, Talia R. (2001). "Predictors of Miscarriages of Justice in Capital Cases." Justice Quarterly 18(4): 949-968.

Harmon, Talia R. (2004). "Race for Your Life: Ana Analysis of the Role of Race in Erroneous Capital Convictions." Criminal Justice Review 29: 76-96.

Hirsch, J. (2000). The Miraculous Journey of Rubin Carter. New York; Houghton Mifflin.

Huff, C. Ronald, Arye Rattner, and Edward Sagarin. (1986). "Guilty Until Proved Innocent:Wrongful Conviction and Public Policy." Crime & Delinquency 32(4): 518-544.

Huff, C. Ronald, and Arye Rattner. (1988). "Convicted but Innocent: False Positives and the Criminal Justice Process." In J.E. Scott and T. Hirschi (Eds.), Controversial Issues in Crime and Justice, Newbury Park CA: Sage, 53-82.

Huff, C. Ronald, Arye Rattner, and Edward Sagrin. (1986). "Guilty Until Proven Innocent: Wrongful Convictions and Public Policy." Crime and Delinquency 32(4): 518-544.

Huff, Ronald, Arye Rattner, and Edward Sagrarin. (1996). Convicted but Innocent: Wrongful Convictions and Public Policy. Thousand Oaks CA: Sage.

Huff, C. Ronald. (2002). "Wrongful Conviction and Public Policy: The American Society of Criminology 2001 Presidential Address." Criminology 40(1): 1 – 18.

Humes, E. (1999). Mean Justice: A Town's Terror, A Prosecutor's Power, a Betrayal of Innocence. New York: Simon & Schuster.

Joy, Peter. (2006). “The Relationship Between Prosecutorial Misconduct and Wrongful Convictions: Shaping Remedies for a Broken System. Wisconsin Law Review 2006: 399 –

Kassin, Saul. (1997). “The Psychology of Confession Evidence.” American Psychologist 52: 221-33.

Knowles, John, Nicola Persico, and Petra Todd. (2001). “Racial Bias in Motor Vehicle Searches: Theory and Evidence.” Journal of Political Economy 109(1): 203-229.

Leo, Richard and Richard Ofshe. (1998). “The Consequences of False Confessions: Deprivations of Liberty and the Miscarriages of Justice in the Age of Psychological Interrogation.” Journal of Criminology and Criminal Law 88: 429-96.

Linscott, S. and R. Frame. (1994). Maximum Security. Wheaton IL: Crossway.

Meissner, C. and J Brigham. (2001). “Thirty Years of Investigating the Own-Race Bias in Memory for Faces---A Meta-analytic Review.” Psychology, Public Policy, and Law 7(1): 3-35.

Miceli, Thomas. (1990). “Optimal Prosecution of Defendants Whose Guilt is Uncertain.” Journal of Law, Economics, and Organization 6: 189-201.

Mustard, David. (2001). “Racial, Ethnic, and Gender Disparities in Sentencing: Evidence from U.S. Federal Courts.” Journal of Law and Economics 44: 285-314.

National Research Council. Identifying the Culprit: Assessing Witness Identification: Washington DC: The National Academies Press.

Parker, Karen, Mari Dewees, Michael Radelet. (2001). “Racial Bias and the Conviction of the Innocent.” In Saundra Westervelt and John Humphrey (Eds.), Wrongfully Convicted: Perspectives on Failed Criminal Justice, Piscataway NJ: Rutgers University Press, 17-35.

Potter, J. and F. Bost. (1997). Fatal Justice: Reinvestigating the MacDonald Murders. New York: Norton.

Protess, D. and R. Warden. (1998). A Promise of Justice: The Eighteen Year Fight to Save Four Innocent Men. New York: Hyperion.

Radelet, Michael, Hugo Adam Bedau, and Constance Putnam. (1992). In Spite of Innocence: Erroneous Convictions in Capital Cases. Boston: Northeastern University Press.

Radelet, Michael, William Lofquist, Hugo Adam Bedau. (1996.) “Prisoners Released from Death Rows Since 1970 Because of Doubts about Their Guilt.” Thomas M. Cooley Law Review 12: 907-966.

Ramsey, Robert and James Frank. (2007). “Wrongful Conviction: Perceptions of Criminal Justice Professionals Regarding the Frequency of Wrongful Conviction and the Extent of System Errors.” Crime & Delinquency 53(3): 436-470.

Raphael, Steven and Michael Stoll. (2013). Why are So Many Americans in Prison? Russell Sage Foundation: New York NY.

Rehavi, M. Marit and Sonja Starr. (2014). “Racial Disparity in Federal Criminal Sentences.” Journal of Political Economy 122(6): 1320-1354.

Reinganum, Jennifer. (1988). “Plea Bargaining and Prosecutorial Discretion.” American Economic Review 78: 713-28.

Ridgeway, Greg. (2006). “Assessing the Effect of Race Bias in Post-traffic Stop Outcomes Using Propensity Scores.” Journal of Quantitative Criminology 22(1): 1-29.

Scheck, Barry, Peter Neufeld, and Jim Dwyer. (2000). Actual Innocence. New York: Doubleday.

Shermer, L. and Brian Johnson. (2010). “Criminal Prosecutions: Examining Prosecutorial Discretion and Charge Reductions in the U.S. Federal District Court.” Justice Quarterly 27:394-95.

Smith, Chris. (2002). “Central Park Revisited.” New York Magazine, October 21, 2002.

Spencer, Bruce. (2007). “Estimating the Accuracy of Jury Verdicts.” Journal of Empirical Legal Studies 4(2): 305-329.

Ulmer, Jeffrey, Todd Light, and John Kramer. (2011). "Racial Disparity in the Wake of the Booker/Fanfan Decision: An Alternative Analysis of the USSC's 2010 Report." Criminology and Public Policy 10:1077-1118.

U.S. Sentencing Commission. (2010). Demographic Differences in Federal Sentencing Practices. Washington DC: U.S. Sentencing Commission.

Wells, Gary and Amy Bradfield. (1988). "Good, You Identified the Suspect: Feedback to Eyewitness Reports Distorts Their Reports of the Witnessing Experience." Journal of Applied Psychology 83: 360-76.

Wells, Gary and Amy Bradfield. (1989). "Distortions Eyewitnesses' Recollections: Can the Post-Identification Feedback be Moderated." Psychological Science 10: 38-144.

Zimmerman, Clifford. (2001). "From the Jailhouse to the Courthouse: The Role of Informants in Wrongful Convictions." In Saundra Westervelt and John Humphrey (Eds.), Wrongfully Convicted: Perspectives on Failed Criminal Justice, Piscataway NJ: Rutgers University Press, 17-35.

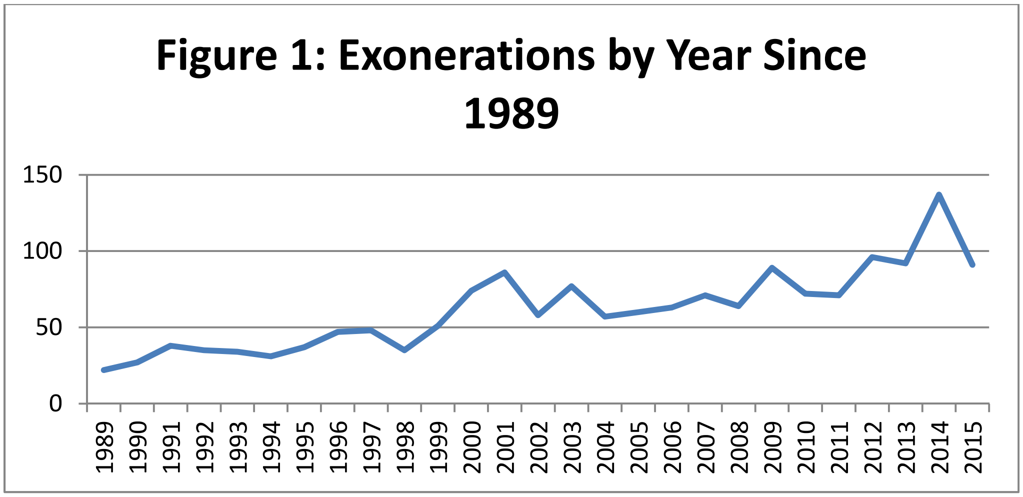

Figure 1: Exonerations by Year Since 1989
150
100
50
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

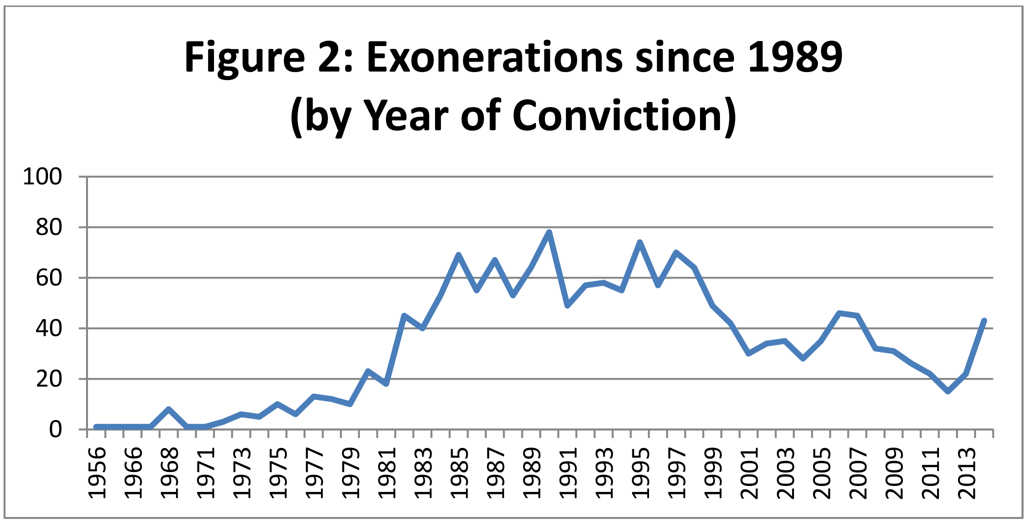

Figure 2: Exonerations since 1989 (by Year of Conviction)
100
80
60
40
20
0
1956
1966
1968
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013

Table1: Exonerations by Crime Type

Crime Type	Number	Percent
Murder	760	45.7
Sexual Assault	276	16.6
Child Sex Abuse	185	11.12
Kidnapping	13	0.78
Robbery/Assault/Oth Violent	156	9.38
Other	273	16.42
	1663	100

Table 2: Exonerations by Crime Type Due to DNA Evidence

Crime Type	Total Exonerations	DNA Exonerations	Fraction DNA Exonerations
All	1663	407	0.24
Murder	760	172	0.23
Sexual Assault	276	191	0.69
Child Sex Abuse	185	26	0.14
Kidnapping	13	5	0.38
Robbery/Assault/Other Violent	156	12	0.08
Other	273	1	0.00

Table 3: Fraction of Exonerations Based on DNA (by Race)

	White	Black
All	0.22	0.32
Sexual Assault	0.58	0.76
Murder	0.27	0.23

Table 4: Comparing Cases with Race Missing/Not Missing

	race missing	race not missing
female	0.253	0.296
Age at Sentencing	30.5	31.7
Convicted for Sexual Assault	0.036	0.033
Convicted for Murder	0.015	0.016

Table 5: Estimated Upper Bound on Ratio of White Wrongful Conviction Rate to Black Wrongful Conviction Rate for Sexual Assault

	States with race data for > 50% of convictions	States with race data for > 25% of convictions	All States
Using DNA Exonerations Only	0.31	0.40	0.37
	(0.05)	(0.08)	(0.06)
	p-val = 0.000	*p-val = 0.000*	*p-val = 0.000*
Using any type of Exoneration	0.49	0.61	0.59
	(0.12)	(0.14)	(0.14)
	p-val = 0.000	*p-val = 0.006*	*p-val = 0.004*
Non-Black vs. Black (DNA Exonerations Only)	0.32	0.40	0.38
	(0.06)	(0.08)	(0.07)
	p-val = 0.000	*p-val = 0.000*	*p-val = 0.000*
1986-2000 (DNA Exonerations Only)	0.25	0.32	0.28
	(0.04)	(0.09)	(0.05)
	p-val = 0.000	*p-val = 0.000*	*p-val = 0.000*

Notes: Standard errors in parentheses (adjusted for sampling error in conviction data). "P-val" corresponds to bootstrapped p-values associated with the null hypothesis that the wrongful conviction rate among white convicts is equal to or greater than it is among black convicts (i.e, that the ratio of the white wrongful conviction rate to the black wrongful conviction rate is greater than or equal to one).

Table 6: Sensitivity of Estimated Ratio of Wrongful Conviction Rates to Excluding Each Year
(Sexual Assault)

	States with race data for > 50% of Convictions			
	Estimate from Column (1) in Table 5	Variation in Estimate Arising From Excluding Each Particular Year		
		Std. Dev.	Min	Max
Using DNA Exonerations Only	0.31 (0.05) *p-val = 0.000*	0.01	0.28	0.32
Using any type of Exoneration	0.49 (0.12) *p-val = 0.000*	0.03	0.40	0.51
Non-Black vs. Black (DNA Exonerations Only)	0.32 (0.06) *p-val = 0.000*	0.01	0.27	0.33
1986-2000 (DNA Exonerations Only)	0.25 (0.04) *p-val = 0.000*	0.01	0.23	0.26

Table 7: Estimated Upper Bound on Ratio of White Wrongful Conviction Rate to Black Wrongful Conviction Rate for Sexual Assault: By Region

	States with race data for > 50% of convictions	States with race data for > 25% of convictions	All States
South			
Using DNA Exonerations Only	0.54	0.57	0.57
	(0.08)	(0.08)	(0.08)
	p-val = 0.004	*p-val = 0.018*	*p-val = 0.003*
Using any type of Exoneration	0.52	0.55	0.55
	(0.08)	(0.09)	(0.09)
	p-val = 0.001	*p-val = 0.004*	*p-val = 0.009*
West			
Using DNA Exonerations Only	0.26	0.28	0.30
	(0.04)	(0.04)	(0.06)
	p-val = 0.000	*p-val = 0.022*	*p-val = 0.109*
Using any type of Exoneration	0.29	0.30	0.32
	(0.05)	(0.05)	(0.06)
	p-val = 0.013	*p-val = 0.058*	*p-val = 0.239*
Northeast			
Using DNA Exonerations Only	0.64	0.63	0.61
	(0.15)	(0.17)	(0.17)
	p-val = 0.000	*p-val = 0.000*	*p-val = 0.000*
Using any type of Exoneration	0.82	0.85	0.80
	(0.24)	(0.26)	(0.25)
	p-val = 0.012	*p-val = 0.010*	*p-val = 0.006*
Midwest			
Using DNA Exonerations Only	0.32	0.37	0.37
	(0.04)	(0.06)	(0.06)
	p-val = 0.000	*p-val = 0.000*	*p-val = 0.000*
Using any type of Exoneration	0.45	0.56	0.55
	(0.09)	(0.15)	(0.15)
	p-val = 0.000	*p-val = 0.002*	*p-val = 0.002*

Notes: Standard errors in parentheses (adjusted for sampling error in conviction data). “P-val” corresponds to bootstrapped p-values associated with the null hypothesis that the wrongful conviction rate among white convicts is equal to or greater than it is among black convicts (i.e, that the ratio of the white wrongful conviction rate to the black wrongful conviction rate is greater than or equal to one).

Table 8: Estimated Upper Bound on Ratio of White Wrongful Conviction Rate to Black Wrongful Conviction Rate for Murder

	States with race data for > 50% of convictions	States with race data for > 25% of convictions	All States
Using DNA Exonerations Only	1.80	1.88	1.84
	(0.33)	(0.35)	(0.34)
	p-val = 0.638	*p-val = 0.697*	*p-val = 0.680*
Using any type of Exoneration	1.00	1.12	1.16
	(0.15)	(0.17)	(0.16)
	p-val = 0.119	*p-val = 0.252*	*p-val = 0.319*
Non-Black vs. Black (DNA Exonerations Only)	1.73	1.80	1.77
	(0.32)	(0.34)	(0.33)
	p-val = 0.627	*p-val = 0.676*	*p-val = 0.633*
1986-2000 (DNA Exonerations Only)	2.03	2.14	2.08
	(0.45)	(0.48)	(0.47)
	p-val = 0.776	*p-val = 0.864*	*p-val = 0.807*

Notes: Standard errors in parentheses (adjusted for sampling error in conviction data). "P-val" corresponds to bootstrapped p-values associated with the null hypothesis that the wrongful conviction rate among white convicts is equal to or greater than it is among black convicts (i.e, that the ratio of the white wrongful conviction rate to the black wrongful conviction rate is greater than or equal to one).

Table 9: Sensitivity of Estimated Ratio of Wrongful Conviction Rates to Excluding Each Year (Murder)

	States with race data for > 50% of Convictions			
	Estimate from Column (1) in Table 8	Variation in Estimate Arising From Excluding Each Particular Year		
		Std. Dev.	Min	Max
Using DNA Exonerations Only	1.80	0.07	1.57	1.88
	(0.33)			
	p-val = 0.638			
Using any type of Exoneration	1.00	0.03	0.91	1.03
	(0.15)			
	p-val = 0.119			
Non-Black vs. Black (DNA Exonerations Only)	1.73	0.07	1.51	1.80
	(0.32)			
	p-val = 0.627			
1986-2000 (DNA Exonerations Only)	2.03	0.12	1.72	2.16
	(0.45)			
	p-val = 0.776			

Table 10: Estimated Upper Bound on Ratio of White Wrongful Conviction Rate to Black Wrongful Conviction Rate for Murder: By Region

	States with race data for > 50% of convictions	States with race data for > 25% of convictions	All States
South			
Using DNA Exonerations Only	1.58	1.69	1.69
	(0.24)	(0.27)	(0.27)
	p-val = 0.652	*p-val = 0.737*	*p-val = 0.769*
Using any type of Exoneration	1.64	1.81	1.81
	(0.3)	(0.4)	(0.4)
	p-val = 0.648	*p-val = 0.827*	*p-val = 0.766*
West			
Using DNA Exonerations Only	0.80	0.73	0.75
	(0.12)	(0.11)	(0.12)
	p-val = 0.234	*p-val = 0.200*	*p-val = 0.278*
Using any type of Exoneration	0.87	0.89	0.97
	(0.16)	(0.17)	(0.18)
	p-val = 0.415	*p-val = 0.379*	*p-val = 0.690*
Northeast			
Using DNA Exonerations Only	3.11	2.95	2.81
	(0.57)	(0.55)	(0.51)
	p-val = 0.382	*p-val =0.198*	*p-val = 0.245*
Using any type of Exoneration	1.97	1.85	1.75
	(0.53)	(0.56)	(0.48)
	p-val = 0.145	*p-val = 0.011*	*p-val = 0.004*
Midwest			
Using DNA Exonerations Only	2.44	2.47	2.47
	(0.49)	(0.48)	(0.48)
	p-val = 0.136	*p-val = 0.341*	*p-val = 0.203*
Using any type of Exoneration	1.93	2.01	2.01
	(0.49)	(0.52)	(0.52)
	p-val = 0.116	*p-val = 0.130*	*p-val = 0.310*

Notes: Standard errors in parentheses (adjusted for sampling error in conviction data). "P-val" corresponds to bootstrapped p-values associated with the null hypothesis that the wrongful conviction rate among white convicts is equal to or greater than it is among black convicts (i.e, that the ratio of the white wrongful conviction rate to the black wrongful conviction rate is greater than or equal to one).

Table A1

State	Number of Exonerations
DE	1
NH	1
VT	1
ND	2
ME	2
ID	2
NM	3
HI	3
WY	3
AK	4
CO	4
SD	4
RI	5
MT	5
AR	5
SC	6
KS	6
MN	8
NV	9
NE	9
WV	9
OR	10
KY	10
UT	11
IA	12
MS	15
DC	15
TN	16
IN	18
CT	18
AZ	18
NJ	19
MD	21
AL	22
GA	26
OK	28
MO	34
WA	37
NC	37
VA	39

MA	41
WI	42
LA	45
PA	53
OH	54
FL	56
MI	60
IL	153
CA	155
NY	203
TX	215
Federal	88

Table A2

State	Exonerations per Million Population
NH	0.81
CO	0.93
DE	1.28
SC	1.50
ID	1.55
ME	1.57
MN	1.63
VT	1.64
NM	1.65
AR	1.87
KS	2.23
NJ	2.26
KY	2.47
HI	2.48
TN	2.81
OR	2.92
IN	2.96
ND	3.11
GA	3.18
FL	3.50
AZ	3.51
MD	3.96
IA	4.10
PA	4.32
NV	4.50
CA	4.58
NC	4.60
OH	4.76
RI	4.77
UT	4.93
AL	4.95
WV	4.98
NE	5.26
MS	5.27
CT	5.29
SD	5.30
VA	5.51
MT	5.54

MI	6.04
WY	6.08
MO	6.08
WA	6.28
AK	6.38
MA	6.46
WI	7.83
OK	8.11
LA	10.07
TX	10.31
NY	10.70
IL	12.32
DC	26.22