Rate of false conviction of criminal defendants who are sentenced to death

Samuel R. Gross[a,1], Barbara O'Brien[b], Chen Hu[c], and Edward H. Kennedy[d]

[a]University of Michigan Law School, Ann Arbor, MI 49109; [b]Michigan State University College of Law, East Lansing, MI 48824; [c]American College of Radiology Clinical Research Center, Philadelphia, PA 19103; and [d]Department of Biostatistics and Epidemiology, University of Pennsylvania School of Medicine, Philadelphia, PA 19104

The rate of erroneous conviction of innocent criminal defendants is often described as not merely unknown but unknowable. There is no systematic method to determine the accuracy of a criminal conviction; if there were, these errors would not occur in the first place. As a result, very few false convictions are ever discovered, and those that are discovered are not representative of the group as a whole. In the United States, however, a high proportion of false convictions that do come to light and produce exonerations are concentrated among the tiny minority of cases in which defendants are sentenced to death. This makes it possible to use data on death row exonerations to estimate the overall rate of false conviction among death sentences. The high rate of exoneration among death-sentenced defendants appears to be driven by the threat of execution, but most death-sentenced defendants are removed from death row and resentenced to life imprisonment, after which the likelihood of exoneration drops sharply. We use survival analysis to model this effect, and estimate that if all death-sentenced defendants remained under sentence of death indefinitely, at least 4.1% would be exonerated. We conclude that this is a conservative estimate of the proportion of false conviction among death sentences in the United States.

capital punishment | criminal justice | wrongful conviction

In the past few decades a surge of hundreds of exonerations of innocent criminal defendants has drawn attention to the problem of erroneous conviction, and led to a spate of reforms in criminal investigation and adjudication (1–3). All the same, the most basic empirical question about false convictions remains unanswered: How common are these miscarriages of justice?

False convictions, by definition, are unobserved when they occur: If we know that a defendant is innocent, he is not convicted in the first place. They are also extremely difficult to detect after the fact. As a result, the great majority of innocent defendants remain undetected. The rate of such errors is often described as a "dark figure" (4)—an important measure of the performance of the criminal justice system that is not merely unknown but unknowable.

However, there is no shortage of lawyers and judges who assert confidently that the number of false convictions is negligible. Judge Learned Hand said so in 1923: "Our [criminal] procedure has always been haunted by the ghost of the innocent man convicted. It is an unreal dream" (5, p. 649). And in 2007, Justice Antonin Scalia wrote in a concurring opinion in the Supreme Court that American criminal convictions have an "error rate of [0].027 percent—or, to put it another way, a success rate of 99.973 percent" (6, p. 182). This would be comforting, if true. In fact, the claim is silly. Scalia's ratio is derived by taking the number of known exonerations at the time, which were limited almost entirely to a small subset of murder and rape cases, using it as a measure of all false convictions (known and unknown), and dividing it by the number of all felony convictions for all crimes, from drug possession and burglary to car theft and income tax evasion.

To actually estimate the proportion of erroneous convictions we need a well-defined group of criminal convictions within which we identify all mistaken convictions, or at least most. It is

hard to imagine how that could be done for criminal convictions generally, but it might be possible for capital murder.

The rate of exonerations among death sentences in the United States is far higher than for any other category of criminal convictions. Death sentences represent less than one-tenth of 1% of prison sentences in the United States (7), but they accounted for about 12% of known exonerations of innocent defendants from 1989 through early 2012 (2), a disproportion of more than 130 to 1. A major reason for this extraordinary exoneration rate is that far more attention and resources are devoted to death penalty cases than to other criminal prosecutions, before and after conviction.

The vast majority of criminal convictions are not candidates for exoneration because no one makes any effort to reconsider the guilt of the defendants. Approximately 95% of felony convictions in the United States are based on negotiated pleas of guilty (plea bargains) that are entered in routine proceedings at which no evidence is presented. Few are ever subject to any review whatsoever. Most convicted defendants are never represented by an attorney after conviction, and the appeals that do take place are usually perfunctory and unrelated to guilt or innocence.

Death sentences are different. Almost all are based on convictions after jury trial, and even the handful of capital defendants who plead guilty are then subject to trial-like-sentencing hearings, usually before juries. All death sentences are reviewed on appeal; almost all are reviewed repeatedly. With few exceptions, capital defendants have lawyers as long as they remain on death row. Everyone, from the first officer on the scene of a potentially capital crime to the Chief Justice of the United States, takes capital cases more seriously than other criminal prosecutions—and knows that everybody else will do so as well. And everyone from defense lawyers to innocence projects to governors and state and federal judges is likely to be particularly careful to avoid the execution of innocent defendants.

This extraordinary difference in resources and attention generates two related effects. (*i*) Advocates for a defendant are much more likely to pursue any plausible postconviction claim of innocence if the defendant is under sentence of death. (*ii*) Courts

Significance

The rate of erroneous conviction of innocent criminal defendants is often described as not merely unknown but unknowable. We use survival analysis to model this effect, and estimate that if all death-sentenced defendants remained under sentence of death indefinitely at least 4.1% would be exonerated. We conclude that this is a conservative estimate of the proportion of false conviction among death sentences in the United States.

(and other government actors) are much more likely to consider and grant such a claim if the defendant is at risk for execution. As a result, false convictions are far more likely to be detected among those cases that end in death sentences than in any other category of criminal convictions.

The high exoneration rate for death sentences suggests that a substantial proportion of innocent defendants who are sentenced to death are ultimately exonerated, perhaps a majority. If so, we can use capital exonerations as a basis for estimating a lower bound for the false conviction rate among death sentences.

Since 1973, when the first death penalty laws now in effect in the United States were enacted (8), 143 death-sentenced defendants have been exonerated, from 1 to 33 y after conviction (mean = 10.1 y) (9). In a previous study we found that 2.3% of all death sentences imposed from 1973 through 1989 resulted in exoneration by the end of 2004 (7). A study by Risinger (10) estimated that had biological samples been available for testing in all cases, 3.3% of defendants sentenced to death between 1982 and 1989 for murders that included rape would have been exonerated by DNA evidence through February 2006. That estimate, however, is based on a small number of exonerations ($n =$ 11) (10). Both studies were limited to convictions that occurred 15 y or more before the study date, and so include a high proportion of all exonerations that will ever occur in the relevant groups. Nonetheless both studies underestimate the false conviction rate for death-sentenced defendants because they do not reflect exonerations that occur after the study period, and do not include false convictions that are never detected at all.

Capital defendants who are removed from death row but not exonerated—typically because their sentences are reduced to life imprisonment—no longer receive the extraordinary level of attention that is devoted to death row inmates. (This applies as well to those who are executed or die on death row from other causes.) If they are in fact innocent, they are much less likely to be exonerated than if they had remained on death row. As a result, the proportion of death-sentenced inmates who are exonerated understates the rate of false convictions among death sentences because the intensive search for possible errors is largely abandoned once the threat of execution is removed.

In other words, the engine that produces an exoneration rate that is a plausible proxy for the rate of false conviction among death-sentenced prisoners is the process of reinvestigation and reconsideration under threat of execution. Over time, most death-sentenced inmates are removed from death row and resentenced to life in prison—at which point their chances of exoneration appear to drop back to the background rate for all murders, or close to it. Thus, we will get a better estimate of the rate of false capital convictions if are able to estimate "what the rate of capital exonerations would be if all death sentences were subject for an indefinite period to the level of scrutiny that applies to those facing the prospect of execution" (7). This study does just that.

Current Study

Data. We examine exonerations among defendants sentenced to death from the beginning of the "modern" death penalty in the United States in 1973, after the Supreme Court invalidated all prior death sentencing laws (11), through the end of 2004. Our data come from two sources. (*i*) Death sentences since 1973 are tracked by the Bureau of Justice Statistics (BJS) of the Department of Justice, which maintains data on the current status of all death-sentenced defendants in that period (12). We know that 7,482 defendants were sentenced to death in the United States from January 1973 through December 2004, and we know when (if ever) each defendant was removed from death row by execution, death by other means, or legal action by courts or executive officials. (*ii*) The Death Penalty Information Center maintains a list of defendants who were sentenced to death in the United States and exonerated since the beginning of 1973 (13), including 117 who were sentenced to death after January 1, 1973 and exonerated by legal proceedings that began before the end of 2004. We collected additional data on these cases from public records and media sources, expanding on the dataset used by Gross and O'Brien (7). We were able to match on several key variables 108 of the 117 death sentence exonerations in this period to specific cases in the BJS database to produce the database we analyzed.

Table 1 displays the status of the 7,482 death-sentenced defendants we studied as of December 31, 2004, the final day of our study period. On that date, 12.6% of these defendants had been executed, 1.6% were exonerated, 4% died of suicide or natural causes while on death row, 46.1% remained on death row, and 35.8% were removed from death row but remained in prison after their capital sentences or the underlying convictions were reversed or modified.

Table 1 is a snapshot of the status of these defendants at the end of the study period. (It would look quite different if it displayed the status of death-sentenced defendants at the end of 1985, for example, or 2000.) It cannot be used directly to estimate the rate of exoneration because exonerations are a function of time. Many of the defendants on death row at the end of 2004 had only been there for a year or two, far less than the mean of 10.1 y from conviction to exoneration for all capital exonerations since 1973.

Over time, many of those who remained on death row at the end of 2004 will be removed (or already have been); most will end up with sentences of life imprisonment. If the pattern for death sentences from 1973 through 1995 holds, over two-thirds of prisoners sentenced to death will have the judgments against them overturned. The majority will remain in prison for life (14, 15), but some will be exonerated and released.

Threat of Execution. A central variable of interest is whether an exoneration took place while the defendant was still under threat of execution (for detailed information, see *SI Materials and*

Table 1. Death-sentenced defendants in the United States, 1973–2004 (n = 7,482)

Status as of December 31, 2004	Proportion of all cases Percent (n)	Time on death row, y Mean (SD)	Time to release, y Mean (SD)
Executed	12.6 (943)	10.7 (4.8)	NA
Died on death row but not executed	4.0 (298)	7.7 (5.9)	NA
Still on death row	46.1 (3,449)	10.5 (6.3)	NA
Removed from death row but not exonerated	35.8 (2,675)	5.4 (4.9)	NA
Exonerated, all	1.6 (117)	6.7 (5.1)	9.1 (5.9)
Exonerated, under threat of execution*	1.4 (107)	7.0 (5.2)	8.6 (5.6)
Exonerated, not under threat of execution†	0.1 (10)	3.6 (2.6)	13.8 (7.5)

NA, not applicable.
*The defendant was exonerated by legal proceedings that were initiated before the end of 2004 and while the defendant was under sentence of death.
†The defendant was exonerated by legal proceedings that were initiated before the end of 2004 but after the defendant was no longer under sentence of death. Data from the Death Penalty Information Center (9) and the BJS of the US Department of Justice (12).

Methods, section 1). The status of the defendant as under threat is obvious when a defendant is exonerated and released directly from death row. On the other side, a defendant is clearly not under threat of execution when the exoneration is the product of a process that began years after removal from death row.

In other cases, determining the threat status of the defendant at the time of exoneration is more demanding. We identify defendants who were under threat of execution to focus on exonerations that benefited from the extraordinary levels of effort and scrutiny that are applied to defendants who might be put to death. Many defendants who leave death row might be sent back. Hence the under-threat-of-execution category includes defendants who were removed from death row but remained eligible for resentencing to death, and in whose cases the prosecution was actively pursuing a new death sentence or considering whether to do so. For example, Ronald Williamson was sentenced to death in Oklahoma in 1988, and awarded a new trial in 1997 because of constitutionally inadequate representation by his trial lawyer (16). He was exonerated by DNA testing 2 y later, in 1999, while awaiting a retrial at which he might have been sentenced to death again. His exoneration was under threat of execution.

We also count an exoneration as under threat if the process that ultimately led to the exoneration began while the defendant was on death row, even if the final decision to release the defendant was made after he left death row. This sort of delay is common for defendants who are removed from death row when their convictions are reversed by reviewing courts but not released until months or years later when the prosecution decides to dismiss the charges. In some cases the process is more elaborate. For instance, John Thompson was sentenced to death in Louisiana in 1985 (13). In 2001 he sought a new trial based on newly discovered evidence, but received only a reduction in his sentence to life imprisonment. Thompson successfully appealed the denial of a new trial and was acquitted in 2003. Thus, although his death sentence was vacated 2 y before his acquittal, we treat him as exonerated under threat of execution because the legal proceedings that led to exoneration began while he was on death row and ran to their conclusion two years later.

We define an exoneration under threat of execution as an exoneration that is the result of legal proceedings that were initiated while the defendant was on death row. The date we assign to an exoneration is the date of removal from death row, the last date on which the exoneration can be initiated and still count as under threat, not the date on which the process was completed. Using these criteria, we determined that 107 of the 117 exonerations that occurred before the end of 2004 were under threat of execution, and 10 exonerations were not under that threat. The significance of this classification is apparent from Table 1. Of defendants sentenced to death since 1973, 35.8% had been resentenced to a prison term by the end of 2004. However, only 8.5% of capital exonerations (10 of 117) came from this group even though these prisoners were, by definition, at a later stage of their imprisonment than those who remained on death row. (Except for those who are exonerated—and a very small group who are resentenced to lesser penalties and eventually released—all prisoners who are sentenced to death do ultimately die in prison. They all start out on death row, some stay there until death by execution by other means, and the rest eventually are moved to the general prison population where they remain until they die.)

Our estimate of the rate of false convictions among death-sentenced defendants is based on the hypothesis that death-sentenced prisoners who remain under threat of execution are far more likely to be exonerated than those who remain in prison but no longer face that threat. We use a Cox proportional hazards model with a time-dependent covariate to test that hypothesis. We find, consistent with expectations, that death-sentenced defendants who are no longer under threat of execution had a rate of exoneration approximately one eighth of that for defendants who remained on death row, 0.131 ($P < 0.0001$) (with 95% confidence interval of 0.064–0.266) (*SI Materials and Methods*, section 3).

Analysis. Our task is to estimate the cumulative probability over time of the event of interest, exoneration, in the population of death-sentenced defendants who remain under threat of execution. The temporal measure (t) is time from conviction. Estimating this probability is complicated by the structure of the
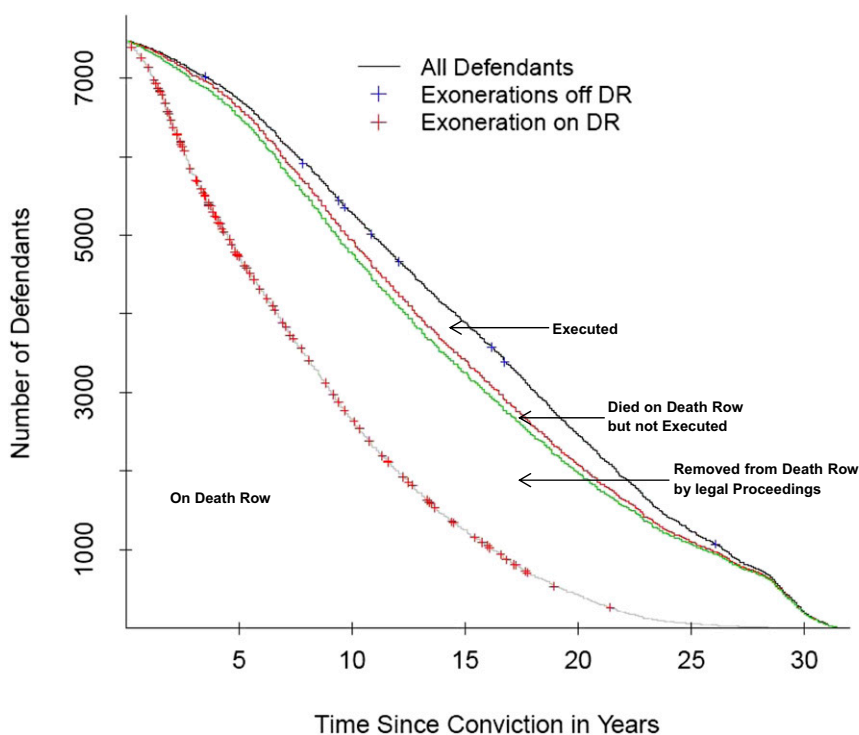

Fig. 1. The status of death-sentenced defendants and the occurrence of exonerations, by time from conviction. The black line represents the total number of all death-sentenced defendants by time from conviction and the gray line the number of defendants who remained on death row (DR) and were therefore available for exoneration under threat of execution by time from conviction. The three areas between the black and gray lines display the dispositions of those defendants who were removed from death row over the time period by mode of removal: execution, suicide or death from natural causes, and legal proceedings (court orders or executive clemency). A minority of defendants who were removed from death by legal proceedings were exonerated. The plus symbols mark exonerations by date measured in time from conviction. The 10 blue plus symbols (on the black line) mark exonerations that were not under threat of execution by the date of the completion of the exoneration. The 107 red plus symbols (on the gray line) mark exonerations that were initiated under threat of execution by the date of removal of the defendants from death row.

population for two reasons. (*i*) Individual defendants joined this population across a 32-y period. Their duration in the study period varied from 1 to 32 y. (*ii*) All death-sentenced defendants began, at conviction, under threat of execution, but for most that threat, and their membership in the population of interest, ended within several years, usually because they were resentenced to life imprisonment. The net effect is that the number of defendants under threat of execution is a decreasing function of time from conviction, ranging from $n = 7{,}482$ at $t = 0$ y to $n = 0$ at $t = 30.7$ y (Fig. 1).

To estimate this cumulative probability, we use survival analysis. This technique has been used in a related context, to estimate the rate of all reversals of death sentences in the United States (15). It is most commonly used, however, to evaluate the efficacy of medical treatments when not all patients experience the outcome of interest. The issue we address is analogous, but the analogy is counterintuitive.

We use survival analysis to assess the prospects of members of a population that is subject to a special risk. In the usual medical context, the condition that defines the population is a pathology such as Lyme disease or diabetes; for our study the defining condition is "death sentence." As a result of this condition, every member of this population is subject to the risk of a terminal event that might remove him from the group that has survived with this condition. In biomedical survival studies, that terminal event that is studied is death from the pathology in question; for our study it is exoneration. This is a counterintuitive equivalence: For our purposes, remaining in prison following a death sentence counts as "survival;" and exoneration, which removes the subject from prison, is analogous to "death" in the common context in which survival analysis is used.

Survival analysis is often used to evaluate the efficacy of a medical treatment that may reduce mortality from a pathology. In this study the "treatment" that lowers the probability of the terminal event of interest (exoneration) is removal from the threat of execution. (This too is a counterintuitive analogy. Exonerating an innocent defendant is, of course, a good thing for that defendant, but removal from death row is equivalent to a treatment that reduces the "risk" of exoneration.) Our focus, however, is not on the treated group (those removed from death row) but on those who remain untreated (defendants who remain under threat of execution and therefore at high risk of exoneration).

In this study, as in medical research, subjects may be removed from the population of interest by means other than the terminal event at issue. In survival analysis of a disease, the usual means of exit by other means are death from a different cause or discontinuation of participation in the study. In our study, all deaths after capital sentencing (by execution, suicide, or natural causes) remove the person from the population that is subject to the risk of execution. However, most removals from the population by means other than exoneration are by legal action that reduces the defendant's sentence to life in prison and thereby eliminates the threat of execution.

A primary difficulty in estimating the cumulative probability of exoneration is that some defendants were censored, i.e., they did not have an opportunity to be exonerated under threat of execution during the study period. Some defendants were removed from that threat during the study period but would have been exonerated had they remained under threat; others, who were sentenced to death relatively recently, remained under threat and had not been exonerated at the end of the study period but would have been exonerated at some later point if the study period were extended. As a result, a simple proportion of exonerated defendants to all defendants is a biased estimate of the cumulative probability of exoneration.

We therefore use the Kaplan–Meier estimator to calculate the cumulative probability of exoneration under threat of execution for death-sentenced defendants, by time from conviction through 2004. This estimator takes account of the censoring of observations caused by recency of incarceration on death row, death from suicide or natural causes, or other removals from the threat

of execution. The Kaplan–Meier survival function estimates the probability of being event-free (remaining on death row) up to a given length of time from conviction. Its complement (1 minus the estimator) estimates the cumulative incidence of the event (exoneration) up to the given length of time from conviction. Unlike a simple proportion, the Kaplan–Meier estimator is unbiased in the presence of independent censoring (see further discussions in *Sensitivity Analysis*), and is completely nonparametric; it can be viewed as a censored data analog of the empirical distribution function. (17, 18) (*SI Materials and Methods*, section 2).

As Fig. 2 shows, the cumulative probability of exoneration for death-sentenced defendants who remained under threat of execution for 21.4 y was 4.1% (with a 95% confidence interval of 2.8–5.2%). [We replicated the Kaplan–Meier estimate of the cumulative probability of exoneration under threat of execution using the Fleming–Harrington estimator. Both results are virtually indistinguishable (*SI Materials and Methods*, section 3).]

This 4.1% estimate may approach the underlying rate of false convictions because it reflects the cumulative effect of a process that is uniquely efficient at detecting such errors. To rely on this estimate, however, two additional steps are necessary.

Sensitivity analysis. An important assumption for the validity of the Kaplan–Meier estimator is that censoring events that remove subjects from consideration are statistically independent of the time to the event of interest if the subjects had not been removed. In this context, that assumption is plausible with respect to censoring by recency of conviction and by death from suicide or natural causes while under threat of execution. On the other hand, there are strong reasons to believe that both execution and removal from death row by legal procedures without exoneration are not independent of time-to-exoneration. Because the assumption of independence may be violated, sensitivity analysis is necessary.

Specifically, (*i*) 13% of death-sentenced inmates were removed from death row by execution (943 of 7,482). Some executed defendants may have been innocent, and, although none has been exonerated after execution (9), they might have been exonerated if they had remained alive and on death row. However, we expect that the proportion of innocent defendants is
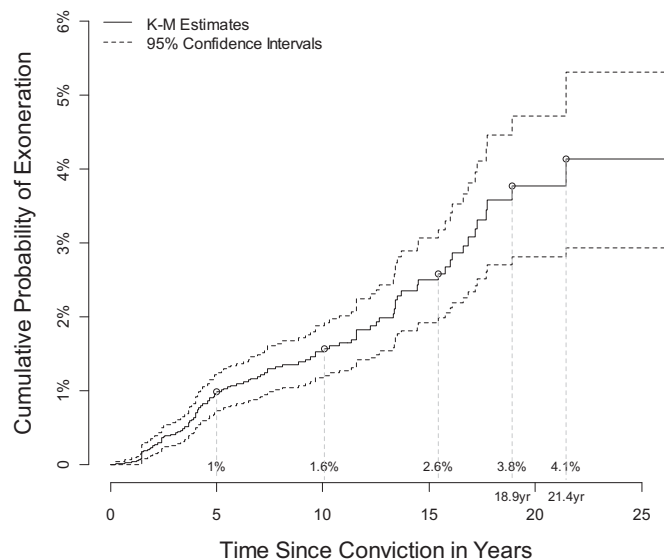

Fig. 2. Kaplan–Meier (K-M) estimate of the cumulative rate of exoneration (solid line) and 95% confidence interval (dashed line) under threat of execution for defendants sentenced to death in the United States from 1973 through 2004 by time from conviction to removal from death row. Exoneration under threat of execution is defined as exoneration that resulted from legal proceedings that were initiated before the end of 2004 and while the defendant was under sentence of death.

lower among those who are executed than among those who remain on death row (7) (*SI Materials and Methods*, section 4). The threat of execution is the engine that drives the process of exonerating innocent death row prisoners, and it is likely that this process becomes more painstaking as inmates approach their execution dates. This concern about executing innocent defendants also drives a second bias: (*ii*) It increases the proportion of innocent defendants among the 36% of death row inmates who were removed from death row and resentenced to prison but not exonerated (2,675 or 7,482). Courts and executive officials explicitly recognize that it is appropriate to take the possibility of innocence into account in deciding whether to reverse a conviction for procedural error or commute a death sentence to life imprisonment, and a wealth of anecdotal evidence suggests that this practice is widespread (*SI Materials and Methods*, section 4). As a result, those who are resentenced to punishments less than death are more likely to be innocent than those who remain on death row.

In short, we believe that (*i*) executed defendants are less likely to have been exonerated if they had remained on death row than those who in fact remained on death row, and (*ii*) defendants who were removed from death row but remained in prison are more likely to have been exonerated if they had remained under threat of execution.

These two biases are not equivalent in magnitude. Nearly three times as many unexonerated death-sentenced defendants were resentenced to prison (2,675) as were executed (943). Even a modest increase in the proportion of innocent defendants among death-sentenced prisoners resentenced to life imprisonment, compared with those who remain on death row, would more than offset a complete absence of innocent defendants among those who are executed.

We use competing risks methodology (18), along with explicit assumptions about the counterfactual probability of exoneration for those who were executed or resentenced to prison, to develop a sensitivity analysis for the Kaplan–Meier estimate of the cumulative exoneration rate. First, we estimate the cumulative incidence of exoneration subject to the competing risks of execution and resentencing by 21.4 y after conviction, on the assumption that censoring by recency, suicide, or natural death was independent of these three event processes. The estimates of the probabilities of removal from risk of exoneration by exoneration under threat of execution, by execution itself, or by resentencing, are 2.2% (1.7%, 2.7%), 23.8% (22.3%, 25.3%), and 48.3% (46.7%, 50.0%), respectively. Thus, a defendant sentenced to death had an estimated 2.2% chance of being exonerated while under threat of execution by 21.4 y after conviction, assuming those executed or resentenced had zero chance of being exonerated (i.e., allowing for the competing risks of execution and resentencing) (*SI Materials and Methods*, section 3).

Consider instead the assumption that, had they remained on death row, (*i*) those who were executed would have had zero chance of exoneration, and (*ii*) those who were resentenced would have had twice the chance of exoneration as the entire population of defendants sentenced to death. This yields the following estimate of the cumulative probability of exoneration, had those who were exonerated or resentenced instead remained on death row: 2.2% + 0% (23.8%) + 2% (2.2%) (48.3%) = 4.4%. Using the Delta method, the confidence interval for this estimate is 3.41–5.28%), assuming that the cumulative incidences of exoneration and resentencing have zero covariance.

A zero probability of exoneration for executed defendants had they remained on death row is necessarily, for the purposes of this estimate, a conservative assumption. We believe that the assumed probability of exoneration for those who were removed from death row and resentenced to prison, twice the mean for the population, is reasonable. We conclude that the Kaplan–Meier estimate we obtained is conservative. Indeed the same result we would obtain if we assume that the probability of exoneration for those resentenced to prison, had they remained

on death row, is value equal to or greater than 1.77 times the population average [2.2% + 0% (23.8%) + 1.77% (2.2%) (48.3%) = 4.1%].

Estimating false convictions from exonerations. Because there is no general method to accurately determine innocence in a criminal case, we use a proxy, exoneration: an official determination that a convicted defendant is no longer legally culpable for the crime for which he was condemned. There will be misclassifications. Some exonerated defendants are guilty of the crimes for which they were sentenced to death. We expect that such errors are rare, given the high barriers the American legal system imposes on convicted defendants in persuading authorities to reconsider their guilt (1–3, 7) (*SI Materials and Methods*, section 4). To date, one such case has come to light, and has been reclassified (19). Monte Carlo simulations reveal that the effect of such misclassifications on the cumulative rate of exoneration is linear: If 10% of exonerated defendants were in fact guilty, the mean cumulative rate of innocence for death-sentenced defendants would be 3.7% rather than 4.1% (95% confidence interval of 3.3–4.0%); if 20% were guilty, the mean rate would be 3.3% (95% confidence interval of 2.8–3.7%) (*SI Materials and Methods*, section 3).

On the other side, some innocent defendants who remained on death row for more than 21.4 y but were not exonerated are misclassified as guilty. Some may still be exonerated; some may be executed; and most will likely die in prison, on death row or off, of natural causes or suicide. In the absence of better data we assume that the probability of a legal campaign to exonerate any prisoner under threat of death who has a plausible innocence claim is 1, and we assume that the probability of success for an innocent prisoner who remains under such threat for at least 21.4 y is also 1. These are necessarily conservative assumptions. To the extent that these probabilities are in fact less than 1, our estimate will understate the actual rate of false convictions.†

The distribution of possible misclassifications is asymmetrical: 216 defendants remained on death row longer than 21.4 y, whereas only 107 were exonerated under threat of execution. Unless the process of death row exoneration is assumed to be unrealistically thorough, it is likely that the number of innocent death-sentenced defendants misclassified as guilty exceeds the number of guilty defendants exonerated under threat of execution and misclassified as innocent. [The proxy we use (the exoneration rate) is also important in its own right: It is a direct measure of the rate of death sentencing of defendants later determined to be legally not guilty.]

Taken together, the sensitivity analysis and the likely net effects of misclassification both point in the same direction and suggest that our 4.1% estimate of the rate of false conviction among death-sentenced defendants is conservative.

Discussion

We present a conservative estimate of the proportion of erroneous convictions of defendants sentenced to death in the United States from 1973 through 2004, 4.1%. This is a unique finding; there are no other reliable estimates of the rate of false conviction in any context. The main source of potential bias is the accuracy of our classification of cases as true or false convictions. On that issue it is likely that we have an undercount, that there are more innocent death row defendants who have not been identified and exonerated than guilty ones who have been exonerated in error.

The most charged question in this area is different: How many innocent defendants have been put to death (6)? We cannot estimate that number directly but we believe it is comparatively

---

†A reviewer of an earlier draft suggested an alternative analytic approach. The suggested approach postulates a campaign process that gives some but not all death-sentenced defendants the opportunity to be exonerated. Identification of the false conviction rate is then based on independence assumptions between innocence and removal from death row. With more complete data of the sort required for the best realization of this insightful approach, we believe that it would offer a particularly valuable supplement, and test of the robustness, of our findings and conclusions.

low. If the rate were the same as our estimate for false death sentences, the number of innocents executed in the United States in the past 35 y would be more than 50 (20). We do not believe that has happened. Our data and the experience of practitioners in the field both indicate that the criminal justice system goes to far greater lengths to avoid executing innocent defendants than to prevent them from remaining in prison indefinitely. One way to do so is to disproportionately reverse death sentences in capital cases in which the accuracy of the defendants' convictions is in doubt and to resentence them to life imprisonment, a practice that makes our estimate of the rate of error conservative. However, no process of removing potentially innocent defendants from the execution queue can be foolproof. With an error rate at trial over 4%, it is all but certain that several of the 1,320 defendants executed since 1977 were innocent (21).

It is possible that the death-sentencing rate of innocent defendants has changed over time. No specific evidence points in that direction, but the number and the distribution of death sentences have changed dramatically in the past 15 y (22). One change, however, is unlikely to have much impact: the advent of DNA identification technology. DNA evidence is useful primarily in rape rather than homicide investigations. Only 13% of death row exonerations since 1973 (18 of 142) resulted from postconviction DNA testing (13), so the availability of preconviction testing will have at most a modest effect on that rate.

Unfortunately, we cannot generalize from our findings on death sentences to the rate of false convictions in any broader category of crime. Capital prosecutions, and to a lesser extent murder cases in general, are handled very differently from other criminal cases. There are theoretical reasons to believe that the rate of false conviction may be higher for murders in general, and for capital murders in particular, than for other felony convictions, primarily because the authorities are more likely to pursue difficult cases with weak evidence of guilt if one or more

people have been killed (23). However, there are no data that confirm or refute this hypothesis.

We do know that the rate of error among death sentences is far greater than Justice Scalia's reassuring 0.027% (6). That much is apparent directly from the number of death row exonerations that have already occurred. Our research adds the disturbing news that most innocent defendants who have been sentenced to death have not been exonerated, and many—including the great majority of those who have been resentenced to life in prison—probably never will be.

This is only part of a disturbing picture. Fewer than half of all defendants who are convicted of capital murder are ever sentenced to death in the first place (e.g., 49.1% in Missouri as in ref. 24, 29% in Philadelphia as in ref. 25, and 31% in New Jersey as in ref. 26). Sentencing juries, like other participants in the process, worry about the execution of innocent defendants. Interviews with jurors who participated in capital sentencing proceedings indicate that lingering doubts about the defendant's guilt is the strongest available predictor of a sentence of life imprisonment rather than death (27). It follows that the rate of innocence must be higher for convicted capital defendants who are not sentenced to death than for those who are. The net result is that the great majority of innocent defendants who are convicted of capital murder in the United States are neither executed nor exonerated. They are sentenced, or resentenced to prison for life, and then forgotten.

1. Garrett B (2011) *Convicting the Innocent: Where Criminal Prosecutions Go Wrong* (Harvard Univ Press, Cambridge, MA).
2. Gross S, Shaffer M (2012) *Exonerations in the United States 1989 Through 2012* (Natl Registry Exonerations, Ann Arbor, MI). Available at www.law.umich.edu/special/exoneration/Documents/exonerations_us_1989_2012_full_report.pdf. Accessed February 4, 2014.
3. Connors E, Lundgren T, Miller N, McEwen T (1996) *Convicted by Juries, Exonerated by Science* (Natl Inst Justice, Washington). Available at www.ncjrs.gov/pdffiles/dnaevid.pdf. Accessed December 28, 2012.
4. Bedau H, Radelet M (1987) Miscarriages of justice. *Stanford Law Rev* 40(1):21–173.
5. *United States v Garrison*, 291 F 646, 649 (SD NY 1923) (Judge Learned Hand).
6. *Kansas v Marsh*, 548 US 163, 182 (concurring opinion of Justice Scalia) (2006).
7. Gross S, O'Brien B (2008) Frequency and predictors of false conviction: Why we know so little, and new data on capital cases. *J Empir Leg Stud* 5:927–962.
8. *Gregg v Georgia*, 428 US 153 (1976).
9. Death Penalty Information Center (2014) Innocence and the Death Penalty. Available at www.deathpenaltyinfo.org/innocence-and-death-penalty. Accessed February 18, 2014.
10. Risinger M (2007) Innocents convicted: An empirically justified factual wrongful conviction rate. *J Crim Law Criminol* 97(3):761–804.
11. *Furman v Georgia*, 408 US 238 (1972).
12. Bureau of Justice Statistics (2005) Capital Punishment in the United States, 1972-2004. Available at www.icpsr.umich.edu/icpsrweb/NACJD/series/10/studies/4430. Accessed October 4, 2011.
13. Death Penalty Information Center (2013) The Innocence List. Available at www.deathpenaltyinfo.org/innocence-list-those-freed-death-row. Accessed January 6, 2013.
14. Liebman J, Fagan J, West V, Lloyd J (2000) Capital attrition: Error rates in capital cases, 1973-1995. *Tex Law Rev* 78:1839–1865.
15. Finkelstein MO, Levin B, McKeague IW, Tsai W-Y (2006) A Note on the Censoring Problem in Empirical Case-Outcome Studies. *J Empir Leg Stud* 3(6):375–395.
16. Grisham J (2006) *The Innocent Man: Murder and Injustice in a Small Town* (Dell, New York).
17. Kaplan EL, Meier P (1958) Nonparametric estimation from incomplete observations. *J Am Stat Assoc* 53:457–481.
18. Kalbfleisch JD, Prentice RL (2002) *The Statistical Analysis of Failure Time Data* (John Wiley & Sons, New York), 2nd Ed.
19. Schwartz J (April 8, 2010) In 3rd trial, conviction in murders from 1985. *NY Times*, Section A, p 13.
20. Bureau of Justice Statistics (2011) Capital Punishment, 2010–Statistical Tables. Available at www.bjs.gov/index.cfm?ty=pbdetail&iid=2236. Accessed April 7, 2014.
21. Death Penalty Information Center (2013) Executions by Year. Available at www.deathpenaltyinfo.org/executions-year. Accessed January 6, 2013.
22. Death Penalty Information Center (2013) Death Sentences in the United States From 1977 By State and By Year. Available at www.deathpenaltyinfo.org/death-sentences-united-states-1977-2008. Accessed January 6, 2013.
23. Gross S (1998) Lost lives: Miscarriages of justice in capital cases. *Law Contemp Probl* 61:125–152.
24. Barnes K, Sloss S, Thaman S (2009) Place matters (most): An empirical study of prosecutorial decision-making in death-eligible cases. *Ariz L Rev* 51:305–379.
25. Baldus D, Woodworth G, Zuckerman D, Weiner N, Broffitt B (2001) Racial discrimination and the death penalty in the post-Furman era: An empirical and legal overview, with recent findings from Philadelphia. *Cornell L Rev* 83(6): 1638–1770.
26. Baime DS (2002) Report to the New Jersey Supreme Court: Systemic Proportionality Review Project 2001-2002 Term, pp 37–39. Available at www.judiciary.state.nj.us/pressrel/baimereport.pdf. Accessed January 8, 2013.
27. Garvey SP (1998) Aggravation and mitigation in capital cases: What do jurors think? *Colum L Rev* 98(6):1538–1576.

Supporting Information

Gross et al. 10.1073/pnas.1306417111

SI Materials and Methods

1. Definitions.

i) The key variable in our analysis is whether a death-sentenced defendant remains under threat of execution. This classification is straightforward with respect to the initial and final threat status of the defendants.

    a) Every one of the 7,482 death-sentenced defendants in our data were, by definition, under threat of execution when he or she was first sentenced to death.

    b) Every defendant who was under sentence of death at the end of the study period, December 31, 2004, is classified as under threat of execution throughout. The great majority of defendants in this category were subject to the same death sentence at all times, but a minority had one death sentence reversed and another imposed for the same crime as the original death sentence.

    c) Any defendant who was not under sentence of death at the end of the study period but who was resentenced to death for the same crime between the end of 2004 and the end 2008 is also treated as under threat of execution throughout. This occurred in a small number of cases (*n* = 31). The classification follows from the outcome: If the defendant was in fact resentenced to death, he or she was under the threat of a new death sentence, which ultimately materialized. We also treat as under threat of execution a somewhat larger set of cases of unexonerated defendants who were removed from death row before the end of 2004 but for whom the available data do not indicate their final dispositions (*n* = 151). Some of these unexonerated defendants might ultimately be resentenced to death; classifying them all as if that will in fact happen makes our estimate of the cumulative rate of exonerations more conservative than it would be under any other choice.

    d) Any defendant whose death sentence was reversed before the end of 2004, and who was not resentenced to death before the end of 2008, is classified as not being under sentence of death at the end of the study period.

ii) In some cases, however, it is difficult to determine when a defendant's status changed from under threat of execution to not under threat of execution. In general, if a defendant's final status is not under threat of execution, the date on which a defendant's death sentence was reversed (sometimes described as "date of removal from death row") is a useful proxy for the date of the change in his or her threat status. However, it is an imperfect proxy because the threat of execution may linger for months or occasionally years after a death sentence is reversed. For example, if a defendant's death sentence is reversed because of legal error in the penalty decision of the defendant's trial, the threat of execution would persist until the prosecutor decided not to seek a second death sentence, or until a judge or jury rejected the prosecutor's attempt to seek such a sentence. In most cases we do not have enough information to determine when a defendant's threat status changed (assuming it did between the time of conviction and the end of the study period). We address this issue in different ways depending on the analysis, as described in sections 2A and 2B below.

2. Introduction to Survival Analysis. *A. Survival analysis.*
Survival data (or time to event data) arise in a number of fields, such as medicine, epidemiology, demography, and sociology. Survival analysis is the statistical methodology for studying the occurrence and time of events (1).

Generally, standard statistical methods do not apply to time to event data due to the following special features. (*i*) The distributional form of failure times is usually not known and so fully parametric methods may be inappropriate (e.g., assuming normality of failure times will generally be unreasonable). (*ii*) Events of interest are usually not observed for all individuals (censoring and truncation). (*iii*) Covariates (explanatory variables) may vary over time. Methods of survival analysis provide a cure to such features.

Some key basic concepts in survival analysis are introduced here informally. (*i*) Time origin: This needs to be well defined for all subjects. (*ii*) The right censoring: A subject would fail after the last observable time point. (*iii*) Independent censoring: The fact that a subject is censored should not convey any information about what their future failure time would be. (*iv*) Survival function: the probability of an individual surviving beyond specific time x (experiencing the event after time x). (*v*) Hazard function: It can be interpreted as the instantaneous conditional failure probability of an event at time x. Due the existence of censoring, it is usually more convenient to model survival time in terms of survival or hazard functions.

B. Survivor function and the Kaplan–Meier estimator. The survivor function or overall survival probability is the probability of being event-free at least up to a given time. The Kaplan–Meier estimator is the most widely used method for estimating survivor functions. It is a nonparametric estimator as it does not assume any distribution of the failure time and only uses the person follow-up time and event status (1, 2).

Mathematical details. To allow for possible ties in data, suppose that the events occur at k distinct times $t_1 < t_2 < \ldots < t_k$. At each distinct time t_i, there are d_i events, and n_i individuals who are at risk to fail. Intuitively, the quantity d_i/n_i provides an estimate of the conditional probability that an individual who survives to just before time t_i will experience the event at time t_i. The Kaplan–Meier estimator is then defined as $\hat{S}(t) = \prod_{j:t_j<t}[1 - (d_j/n_j)]$, for $t_1 \leq t \leq t_k$, where $S(t)$ is the underlying survivor function at time t, and $\hat{S}(t)$ is the Kaplan–Meier estimator for survivor function. The Kaplan–Meier estimator thus is a step function with jumps at the observed event times. The sizes of these jumps depend not only on the number of events observed at each event time, but also on the pattern of the censored observations before these corresponding times.

The variance of the Kaplan–Meier estimator can be estimated by Greenwood's formula, namely $\widetilde{Var}[\hat{S}(t)] = [\hat{S}(t)]^2 \sum_{j:t_j<t}\{d_j/[n_j(n_j - d_j)]\}$. An approximate 95% confidence interval for $S(t)$ is $\hat{S}(t) \pm 1.96 \times \widetilde{Var}[\hat{S}(t)]^{\frac{1}{2}}$.

In this paper, the probability of not being exonerated (survival function) for exonerations under threat and the corresponding 95% confidence intervals are obtained by the Kaplan–Meier estimator and Greenwood's formula. For easier interpretation, the cumulative probability of exoneration for exonerations under threat of execution, which is one minus survivor function, is obtained and presented here.

An illustrative example. Let us consider death as the event of interest. Suppose 100 cancer patients lived for at least 1 y since surgery, 10 died and 10 were lost to follow up at the end of the first year, and 20 more died at the end of the second year. Therefore, the estimated 1-y and 2-y survivals are 90/100 = 90% and 60/80 = 75%, and the estimated survivor function (Kaplan–Meier estimator) up to (and including) 2 y is thus 90% × 75% = 67.5%.

C. An alternative estimator. The Fleming–Harrington estimator (3) is an alternative method to estimate the survivor function, and is

asymptotically equivalent to the Kaplan–Meier estimator. When there are no tied failure times, the Fleming–Harrington estimate is the exponentiation of the negative Nelson–Aalen estimate of the cumulative hazard function. As the following figure shows, for our analysis the Fleming–Harrington estimate is indistinguishable from the Kaplan–Meier estimate displayed in Fig. 2.

3. Other Statistical Methods.

i) We used a Cox proportional hazards model to estimate the relative risk of exoneration for death-sentenced defendants who were no longer under threat of execution compared with death-sentenced defendants who remained under threat of execution. In this analysis we treated the defendant's threat status as a time-dependent covariate, using time of removal from death row as a proxy for time of removal of threat of execution for those defendants who were not returned to death row. Univariate analysis indicated that the relative risk is 0.131 ($P < 0.0001$; with a 95% confidence interval of 0.064–0.266).

ii) For the Kaplan–Meier analysis, we use time from conviction to removal from death row not as a proxy but as an explicit measure of duration. As we state in the legend of Fig. 2, we estimate the cumulative rate of exoneration under threat of execution for defendants sentenced to death in the United States from 1973 through 2004, by time from conviction to removal from death row. That choice creates no apparent bias. It does, however, leave one last task: For each of the 117 exonerations in the data we have to determine whether at the time it occurred the defendant was still under threat of execution. That classification is described in the legend of Fig. 2 where an exoneration under threat of execution is defined as exoneration that resulted from legal proceedings that were initiated before the end of 2004 and while the defendant was under sentence of death. Fortunately, the exonerations in the data were sufficiently well publicized and well documented that we are able to make these determinations with little difficulty.

The status of the exonerated defendant as under threat is obvious in cases such as Leroy Orange, who spent 19 y under sentence of death in Illinois before he was pardoned by the governor and released directly from death row (4). On the other side, Randall Dale Adams was clearly not under threat of execution when he was exonerated in 1989. He was sentenced to death in Texas in 1977, removed from death row to the general prison population in 1980 as a result of a Supreme Court decision that the jury selection procedure at his trial (and many others) was unconstitutional, and exonerated 9 y later as a result of a series of events initiated by a documentary movie about his case that was first conceived in 1985 (4).

In other cases, determining the threat status of the defendant at the time of exoneration is more demanding. Our purpose in identifying defendants who were under threat of execution is to focus separately on those exonerations that benefited from the extraordinary levels of effort and scrutiny that are applied to defendants who might be put to death. A defendant who has left death row but who might be sent back there remains under threat of execution, so the under-threat-of-execution category also includes exonerated defendants who were removed from death row but remained eligible for resentencing to death because the prosecution was either actively pursuing a new death sentence or had not yet decided whether to do so. For example, Ronald Williamson was sentenced to death in Oklahoma in 1988, and awarded a new trial while on death row in 1997 because of ineffective assistance of trial counsel. He was exonerated by DNA testing 2 y later in 1999 while awaiting a retrial at which he might have been sentenced to death again (4).

We count an exoneration as under threat of execution if the legal process that ultimately led to the exoneration began while the defendant was on death row, even if the final decision to release the defendant was some time after he left death row. This is common for defendants who are removed from death row when their convictions are reversed by reviewing courts, and who are then released and exonerated several months or even years later when the prosecution decides to dismiss the charges. In some cases that process is more elaborate. For instance, John Thompson was sentenced to death in Louisiana in 1985. In 2001 he sought a new trial based on newly discovered evidence of innocence, but received only a reduction of his death sentence to a sentence of life imprisonment. Thompson successfully appealed the denial of a new trial, and was later acquitted in 2003 (4). Thus, although his death sentence was vacated 2 y before his acquittal, we treated him as having been under threat of execution until the time of exoneration because the legal procedures that led to his exoneration began while he was on death row and subject to the intense scrutiny that is focused on defendants who might be put to death.

iii) The competing risks approach we use for our sensitivity analysis estimates the type-specific cumulative incidences for the marginal event (i.e., the distribution had censoring by recency or natural death been removed). Mathematically, these type-specific cumulative incidences are given by $P(T < t, J = j)$, where T is the time to removal from death row and J indicates the event type (with $J = 1$ denoting exoneration, $J = 2$ denoting execution, and $J = 3$ denoting resentencing).

The sum of the type-specific cumulative incidences goes to one in the limit, as time increases, because $P(T < t, J = 1) + P(T < t, J = 2) + P(T < t, J = 3) = P(T < t)$. Further, the estimate of this sum can be one at the end of the study if the last observation is an event of any of these three types (exoneration, execution, and resentencing)—as opposed to censoring by recency or death by other means—however, at all times before the last such event this sum will be strictly less than 1. Thus, our estimated cumulative incidences sum to less than 1 because we estimate them at the time of the last exoneration, 21.4 y, which is before the time of the last execution and/or resentencing.

iv) In Fig. S2 we illustrate a few alternative sensitivity analysis results, and contrast them with the Kaplan–Meier estimate. In *Sensitivity analysis*, we display a sensitivity analysis result assuming that, had the defendants remained under threat of execution, (*i*) those who were executed would have had zero chance of exoneration, and (*ii*) those who were resentenced to a lesser penalty would have had twice (2×) the chance of exoneration as the entire population of defendants sentenced to death. Here we also present two additional sensitivity analysis results: first, assuming those who were resentenced would have had the same (1×) and second, assuming they would have had three times (3×) the chance of exoneration as the entire population of defendants sentenced to death. (For both analyses, we continue to assume that had they remained under threat of execution, defendants who were executed would have had zero chance of exoneration.) One may view the 1× chance sensitivity analysis as a lower-bound estimate because the chance of exoneration for those who were resentenced should be much higher than that for the entire population, and the 2× and 3× chance analyses as alternative plausible estimates.

v) We used a Monte Carlo simulation to assess the robustness of treating exoneration under threat of execution as a proxy for innocence. We assumed that p% of exonerated defendants were in fact guilty of the crimes for which they were sentenced, and therefore randomly selected p% of these exonerated defendants to be removed from death row and resentenced to life imprisonment. The Kaplan–Meier estimator was then calculated to determine the cumulative rate of innocence for 1,000 replications of such hypothetical populations. We found that if 10% exonerated defendants were

assumed to be guilty, the mean cumulative rate of innocence for death-sentenced defendants would be 3.68% (with a 95% confidence interval of 3.26–3.96%); if 20% were assumed to be guilty, the mean innocence rate would be 3.29% (with a 95% confidence interval of 2.76–3.69%); and so forth.

4. The Effect of Possible Innocence on the Review of Death Sentences. In theory, legal review of a criminal conviction in the United States focuses primarily on procedural errors at trial rather than on the factual accuracy of the trial court's judgment. In general, for all criminal appeals, this theory may be honored primarily in the breach (5). In the context of review and modification of death sentences, however, this general rule is explicitly abandoned because of the high level of concern about the danger of putting an innocent defendant to death.

As a result, we are confident that death-sentenced defendants who can present substantial claims of factual innocence, but who are not exonerated, are more likely than other death-sentenced defendants to have their death sentences reversed by judicial decision or by executive order, even though they remain in prison. Specifically,

i) In the case of *Herrera vs. Collins* (6), a majority of Supreme Court justices agreed that an innocent defendant has a constitutional right not to be executed even if there are no specific constitutional errors in the proceedings that produced his death sentence. There is no suggestion of a parallel right to freedom for an innocent defendant who has been sentenced to prison, even for life, regardless of how strong the evidence of his innocence may be. In general, American courts are reluctant to reverse or even reconsider the guilt of convicted defendants.*,†,‡ *Herrera vs. Collins* illustrates how much more willing courts are to take action when the issue at stake is the execution of a defendant who may be innocent. One reason is the unique fear of putting an innocent person to death. In addition, and equally important, execution can be avoided without freeing a defendant who was convicted of a heinous murder, and who, despite all doubts and uncertainties, may well have committed it. All that is required is to reduce the defendant's sentence to life imprisonment—which happens to most death-sentenced defendants anyway, whether or not they have substantial claims of innocence.

ii) In the case of *Schlup vs. Delo* (10), the Supreme Court held that a defendant who produces strong evidence of innocence may be allowed to pursue legal claims unrelated to innocence that other prisoners would not be allowed to pursue. Some

states have passed similar laws (11). Although this right applies in theory to all imprisoned defendants, it has been used primarily by possibly innocent prisoners under sentences of death. Many of them, including Lloyd Schlup, the defendant whose case was decided by the Supreme Court, are ultimately removed from death row but not exonerated (11).

iii) One of the basic principles of American appellate review is the harmless error rule under which procedural error is not sufficient to reverse a judgment unless the error is likely to have affected the outcome of the trial (12, 13). Error is more likely to affect the outcome, and therefore to be considered harmful and warrant reversal, if the evidence of guilt is weak or in serious dispute. That is common in cases in which innocent defendants are convicted of murder, but uncommon in ordinary murder cases where there is usually no doubt about defendants' guilt.

iv) Harmful error in a capital case includes any violation of the defendant's rights that contributed to a sentence of death that might otherwise have been avoided. In addition, the possibility that a capital defendant who has been convicted of murder might still somehow be innocent is an important factor in deciding whether to sentence him to death or to a life sentence in the first place§ (15). This means that courts reviewing death sentences are more likely to find harmful errors on the question of punishment—and to reduce death sentences to life imprisonment—in cases in which the defendant's guilt is in doubt.

v) In some states appellate courts review the propriety of death sentences, which gives them the power to reduce death sentences in cases in which the guilt of the defendant is not clear. (For example, the Mississippi Supreme Court explicitly recognizes a heightened standard of appellate scrutiny in capital cases. In *Porter vs. Mississippi* (16), it explained that "what may be harmless error in a case with less at stake becomes reversible error when the penalty is death." In *California vs. Ramos* (17), the US Supreme Court required a greater degree of judicial scrutiny in capital cases because of the qualitative difference between death and all other punishments.)

vi) The possibility that a death-sentenced defendant might be innocent is a frequent factor in decisions by executive officers to commute the defendant's sentence from death to life imprisonment (18)—presidents, e.g., Bill Clinton in 2001 (18–20), or state governors, e.g., George Bush¶ of Texas in 1998 (18, 20) or John Kasich of Ohio in 2011 (18, 21).

5. Human Subjects Exemption. On August 11, 2011 the Social Science/Behavioral/Education Institution Review Board of Michigan State University determined that the research for this study, IRB no. 11-777, "does not involve human subjects" as defined by CFR 46.102(f).

---

*For example, in *Jackson vs. Virginia* (7), the Supreme Court cited as a familiar standard that the question before a court on review is not "whether it believes that the evidence at the trial established guilt beyond a reasonable doubt" but rather "whether, after viewing the evidence in the light most favorable to the prosecution, any rational trier of fact could have found the essential elements of the crime beyond a reasonable doubt."

†Appellate courts reviewing convicted defendants' claims of insufficient evidence of guilt have frequently pointed out how rarely such a claim succeeds. See, for example, *Fisher vs. Indiana* (8), in which the Indiana Supreme Court observed that "[c]ourts of review rarely reverse a jury's guilty verdict on insufficiency of evidence grounds."

‡For example, in *Ervin vs. Texas* (9), the Texas Court of Appeals recognized that appellate courts have only rarely and reluctantly exercised the power to reverse convictions based on the factual inadequacy of the evidence of the defendant's guilt.

§Courts consider doubts about the evidence of the defendant's guilt—even when legally sufficient to sustain the conviction—in reviewing the appropriateness of the death penalty. For example, in *Tarver vs. Hopper* (14), the US Court of Appeals for the Eleventh Circuit noted that "the best thing a capital defendant can do to improve his chances of receiving a life sentence ... is to raise doubt about his guilt."

¶Governor Bush is quoted as saying, "The first question I ask in each death penalty [commutation] case is whether there is any doubt about whether the individual is guilty of the crime ...While Henry Lee Lucas is guilty of committing a number of horrible crimes, serious concerns have been raised about his guilt in this case" (20).

1. Kalbfleisch JD, Prentice RL (2002) *The Statistical Analysis of Failure Time Data* (Wiley & Sons, Hoboken, NJ), 2nd Ed.
2. Klein JP, Moeschberger ML (2003) *Survival Analysis: Techniques for Censored and Truncated Data* (Springer, New York), 2nd Ed.
3. Fleming TD, Harrington DP (1984) Nonparametric estimation of the survival distribution in censored data. *Comm Stat-Theor M* 13(20):2469–2486.
4. Death Penalty Information Center (2012) The Innocence List. Available at www.deathpenaltyinfo.org/innocence-list-those-freed-death-row. Accessed December 27, 2012.

5. Mathieson AR, Gross S (2003) Review for error. *Law Probab Risk* 2(4):259–268.
6. *Herrera v Collins*, 506 US 390 (1993).
7. *Jackson v Virginia*, 443 US 307, 318–319 (1979).
8. *Fisher v Indiana*, 810 NE2d 674, 677 (2004).
9. *Ervin v Texas*, 331 SW3d 49 (2010).
10. *Schlup v Delo*, 513 US 298 (1995).
11. O'Brien S (2009) Mothers and sons: The Lloyd Schlup story. *UMKC Law Rev* 77:1021–1047.
12. *Neder v US*, 527 US 1 (1999).

13. Rule 52, *Fed Rules Crim Proc.*
14. *Tarver v Hopper*, 169 F3d 710, 715–716 (11th Cir., 1999), p 52.
15. Garvey SP (1998) Aggravation and mitigation in capital cases: What do jurors think? *Colum. L. Rev* 98(6):1538–1563.
16. *Porter v Mississippi*, 732 So2d 899, 902 (1999).
17. *California v Ramos*, 463 US 992, 999 (1983).
18. Death Penalty Information Center (2012) Available at www.deathpenaltyinfo. org/clemency. Accessed December 27, 2012.
19. US Department of Justice (January 20, 2001) Commutations, Remissions and Reprieves Granted by President William J. Clinton (1993-2001). Available at www. justice.gov/pardon/clinton_comm.htm. Accessed December 27, 2012.
20. *CBS News* (June 6, 1998). Bush Commutes Death Sentence. Available at www.cbsnews. com/stories/1998/06/26/national/main12682.shtml. Accessed December 27, 2012.
21. Johnson A (June 9, 2011) Kasich spares prisoner's life; there's doubt inmate committed murder, but he shouldn't be freed, governor says. *The Columbus Dispatch*, Section B, p 1.
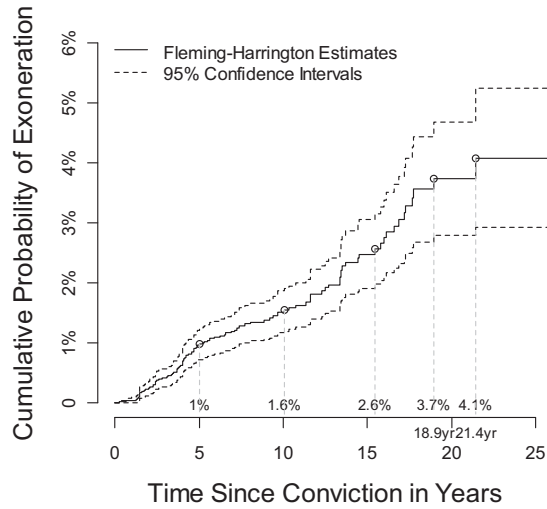
Fig. S1. Fleming–Harrington estimate of cumulative probability of exoneration.
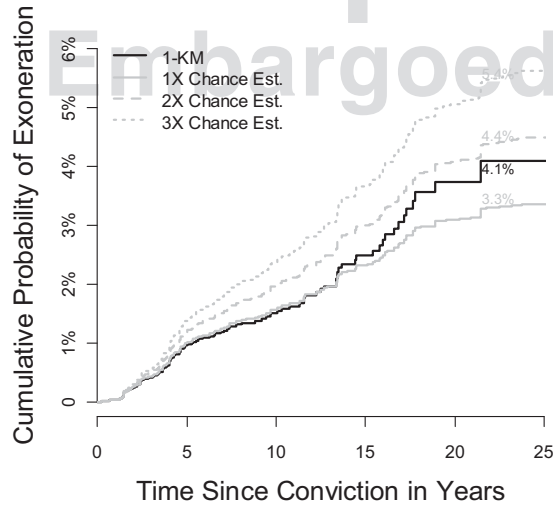

Fig. S2. Results of alternative sensitivity analyses contrasted with results of the Kaplan–Meier (KM) estimate.