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The Unrealized Promise of Forensic Science

An Empirical Study of its Production and Use

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The Unrealized Promise of Forensic Science -- An Empirical Study of its Production and Use

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ABSTRACT

In theory, forensic science provides independent, objective, dispassionate evidence in proceedings often charged with emotion and the failings of human recollection. But how does it work in practice? We collected data on the prevalence and use of forensic evidence in five jurisdictions across the United States. We also analyzed existing data on crime labs and conducted an experimental survey of prosecutors and criminal defense attorneys to measure the effect of forensic evidence on the plea-bargaining process.

Our findings are sobering. Despite considerable investment in forensic databases and crime laboratory upgrades to improve capacity, forensic evidence is still being analyzed in only a small fraction of cases in which it is available. Moreover, it is typically used post-arrest to confirm suspicions rather than as an independent diagnostic tool to identify suspects. While forensic evidence is regularly used in homicides, its use is highly limited by resource constraints, resulting in long turnaround times for less serious offenses, which encourage police to and prosecutors rely on other types of evidence. As a result, the full potential of forensic evidence remains unrealized.

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"The darkened courtroom; the awed silence of the assembly; the intense mental strain on those more deeply interested; the awful force of the blow to the guilty man when he first beholds the evidence of his crime illumined by the light of scientific test." [1]

INTRODUCTION

In theory, forensic science offers enormous promise to the criminal justice system. Supplementing the vagaries of human memory and the suspicions of the police with a process that is more objective and that is at least partly independent of the conventional criminal justice process should improve the overall reliability of the system.[2] As forensic evidence databases continue to grow, they should yield investigative leads with greater and greater regularity. In theory, forensic science should increase the speed and certainty of arrests and thereby reduce costs associated with investigation and court processing.[3] This might in turn free up resources to investigate more difficult cases with greater care. At trial, independent and objective scientific analysis should serve as a vital check against adversarial processes often charged with emotion and the failings of human recollection, as DNA exonerations demonstrate.

But how does it work in practice? Older research suggests that apart from homicides, forensic evidence was collected and tested in a surprisingly low fraction of cases.[4] Even in cases in which forensic evidence was used it was not

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[1] Percy Edwards, *Chemical Experts—A Trio of Important Factors in the Detection of Crime*, 42 CENT. L.J. 323, 323 (1896).

[2] *See* CHARLES PERROW, NORMAL ACCIDENTS: LIVING WITH HIGH-RISK TECHNOLOGIES (1984) (noting importance of independent uncoupled systems to increase system reliability); James M. Doyle, *Learning from Error in American Criminal Justice*, 100 J. CRIM L. & CRIMINOLOGY 109 (2010) (calling for criminal law to view wrongful convictions as organizational accidents and to create, like medicine and aviation, a culture of safety).

[3] Joseph Peterson, S. Mihaljlovic, and M. Gilliand, FORENSIC EVIDENCE AND THE POLICE: THE EFFECTS OF SCIENTIFIC EVIDENCE ON CRIMINAL INVESTIGATIONS (1984) (clearance rates of offenses with evidence scientifically analyzed were about three times greater than in cases where such evidence was not used); John Roman, S. Reid, J. Reid, A. Chalfin, W. Adams, and C. Knight, THE DNA FIELD EXPERIMENT: COST-EFFECTIVENESS ANALYSIS OF THE USE OF DNA IN THE INVESTIGATION OF HIGH VOLUME CRIMES, 2008 (solution rates of property crime and prosecution rate were twice as high when DNA evidence was collected as when it was not); M. Briody, The Effects of DNA Evidence on the Criminal Justice Process (2004) (homicide cases with DNA evidence more likely to be prosecuted and juries more likely to convict). Jennifer L. Mnookin, *Idealizing Science and Demonizing Experts: An Intellectual History of Expert Evidence* 52 VILLANOVA L. REV. 101, 133 (noting that this has long been the case: "Science, with its promise of disinterested observation and objectivity, seemed to offer a promising method for generating dispositive evidence.").

[4] Joseph Peterson, Ira Sommers, Deborah Baskin, and Donald Johnson, THE ROLE AND IMPACT OF FORENSIC EVIDENCE ON THE CRIMINAL JUSTICE PROCESS 8 (2010) (for study using crime data from 2003, noting that with exception of homicides, "overall percent of reported crime incidents that had physical evidence examined in crime labs was low." For aggravated assaults in the study sample, evidence was collected in 30.3% of cases and examined in 9.2%; for burglaries the

typically analyzed until after a suspect has been arrested -- meaning that forensic evidence played no role in initially identifying a suspect, arguably the stage at which objective evidence is most critical.[5] One of the reasons that forensic evidence was underused was that the quantity of unanalyzed or "backlogged" evidence was staggering,[6] which suggests that forensic evidence was not being efficiently collected or analyzed. But are backlogs the result of valuable evidence that was untested or the overcollection of useless evidence, or both?[7]

Since this research was conducted, crime laboratories have experienced considerable growth.[8] In addition, the popularity of forensic evidence and analysis has continued to increase among the general public, due in part to fictional television programs, romanticizing the role of forensic science in solving crimes. Some prosecutors have expressed concern that these shows give

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corresponding rates were 19.6% and 9.2%; for rapes, 63.8% and 18.6%, 24.8% and 9.9%, but for homicides, the rates were 97% and 81%) In recent years, the use of DNA evidence in property crimes has increased somewhat. John K. Roman, Shannon Reid, Jay Reid, Aaron Chalfin, William Adams, Carly Knight, ANALYSIS OF THE USE OF DNA IN THE INVESTIGATION OF HIGH-VOLUME CRIMES (2008). However, most crime labs still treat property crime as a low priority. For example, the Utah Bureau of Forensic Services DNA case acceptance criteria explicitly state that crimes against persons will be given priority over property crimes, and that only two items of evidence may be submitted for each property crime.

[5] Peterson et al. *supra* note 4. Historically, even fingerprint evidence was seldom used to identify suspects. Peter W. Greenwood, THE RAND CRIMINAL INVESTIGATION STUDY: ITS FINDINGS AND IMPACTS TO DATE 4 (1979) ("The reason for this surprising finding [that fingerprint recovery rate was unrelated to case solution] appeared to be that most police departments did not have adequate resources devoted to their latent search capability. They were unable to utilize those prints that were lifted. In most departments, latent prints were only utilized to confirm the identity of a suspect which had been established in some other way.") One study noted that the most frequently cited reason for the lack of forensic testing (even in cases where DNA evidence was available) was the lack of a suspect. Kevin J. Strom & Matthew J. Hickman, *Unanalyzed Evidence in Law Enforcement Agencies: A National Examination of Forensic Processing in Police Departments*, 9 Criminology and Public Policy 381 (2010) (Numerous unsolved homicide and rape cases contained forensic evidence (including DNA) that had not been submitted to laboratory; Lack of a suspect in the case was most frequently cited reason for not submitting forensic evidence for analysis).

[6] Mark Nelson, MAKING SENSE OF DNA BACKLOGS, 2010—MYTHS VS. REALITY (National Institute of Justice 2011) ; Matthew Durose CENSUS OF PUBLICLY FUNDED FORENSIC CRIME LABORATORIES, 2005, (2008) (noting that typical laboratory performing DNA testing begun 2005 with 86 backlogged requests for DNA analysis and finished the year with a backlog of 152 requests").

[7] See e.g. Jessica Genza, *Victim's Hopes for Justice Fade as Rape Kits are Routinely Ignored or* Destroyed, The Guardian, November 10, 2015 (chronicling cases of police discarding rape kits); As Nelson, *supra* noted, "more research is needed to completely understand how law enforcement decide to submit or not submit evidence to a laboratory, what proportion of open cases could benefit from forensic testing and how cases should be prioritized for testing." *Id. at 5.*

[8] Between 2002 and 2009, full-time personnel employed at publicly-funded crime laboratories increased 19 percent, total budgets increased 60 percent, and the number of requests for analysis rose from 2.7 million to 4.1 million. Matthew Durose et al., *Census of Publicly Funded Crime Laboratories, 2009*, Bureau of Justice Statistics (2012). Forensic biology casework requests jumped from 61,000 to 343,000. Durose, *supra* note 35 and Matthew Durose, *Census of Publicly Funded Crime Laboratories, 2005*, Bureau of Justice Statistics (2008).

jurors unrealistic expectations for conclusive and easy to understand forensic evidence in criminal cases, termed the "CSI Effect."[9] How these perceptions of forensic evidence influence police collection of evidence and attorneys' decisions to resolve a case through plea bargaining or trial has not been previously explored.

We also know little about how the influence of particular types of forensic evidence differentially influences attorneys' plea-bargaining decisions. Do pieces of forensic evidence that are more individualizing (e.g. DNA evidence) have more influence on plea bargaining decisions that pieces of evidence that are more associative (e.g., tire tread patterns)? Does a more complete DNA match produce different plea bargain/trial decisions as opposed to a partial DNA match? Or does the mere presence of inculpatory evidence override any information the analyses provide?

Serious questions about the way in which forensic science is practiced have also been raised. False or misleading forensic science testimony is an important factor in many wrongful convictions.[10] The National Academy of Sciences and the National Research Council have criticized both the scientific basis of some widely-used forensic science disciplines and the way in which they are presented in the courtroom.[11] The President's Council on Science and Technology was also highly critical of the use of comparison methods in

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[9]*See* Donald Shelton, *A Study of Juror Expectations and Demands Concerning Scientific Evidence: Does the 'CSI Effect' Exist?* 9 VANDERBILT J. OF ENT. & TECH. L. 330 (2006); Kimberlianne Podlas, *The CSI Effect and Other Forensic Fictions*, 27 LOYOLA ENT. L. REV. 87 (2006); Dennis Stevens, *Forensic Science, Wrong Convictions, and American Prosecutor Discretion*, 47 HOWARD J. OF CRIM. J. 31 (2008) (noting that some jurors possessed unrealistic expectations about forensic analyses);Kathianne Boniella, *CSI has Ruinied the American Justice System,* THE NEW YORK POST, September 27, 2015 (interviewing prosecutors and defense counsel about changing juror expecations in criminal cases).

[10] See e.g. Kelly Servick, *Sizing Up the Evidence*, 351 SCIENCE 1130 (2016) (noting widespread problems in many disciplines of forensic science widely used by FBI and other forensic laboratories, particularly with respect to forensic scientists overstating strength of evidence against defendant; Mike Wagner & Lucas Sullivan, *Defense Attorneys Launch Review of Forensic Scientist's Cases,* THE COLUMBUS DISPATCH, Friday, November 4, 2016 (noting problems with work of forensic scientist that favored police and prosecutors and led to several wrongful convictions); Mark Hansen, *Long-Held Beliefs about Arson Science have been Debunked after Decades of Misuse,* AMERICAN BAR ASSOCIATION JOURNAL, December 2015 (forensic evidence at heart of prosecution's arson case was debunked by post-trial scientific developments); Barry Scheck & Peter Neufeld, ACTUAL INNOCENCE 204-21 (2000) (chronicling role of "junk science" in wrongful convictions); Dahlia Lithwick, *Crime Lab Scandals Just Keep Getting* Worse, SLATE October 29, 2015 (Massachusetts crime lab analyst admitted to falsifying thousands of drug tests; noting that crime lab scandals have occurred in 20 states and the FBI); see *also* Caitlin Plummber & Imran Syed, 'Shifted Science' and Post-Conviction Relief, 8 STAN. J. C.R. & C.L. 259 (2012) (discussing problems that developments in science poses for criminal justice system which seeks finality).

[11] National Research Council, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD, 2009.

forensic science.[12] Others have noted the gap in cultures between forensic scientists, who typically know in advance what police and prosecutors are hoping to prove, and other scientists, who use double-blind studies to guard against confirmation bias.[13] Commentators have suggested a variety of remedies including making labs independent and requiring standardized laboratory and analyst certification.[14] Yet we lack basic knowledge of how independence or certification affects the production and use of forensic science.

In short, there is a pressing need for research on how forensic evidence is gathered, tested, used, and presented from the moment that a crime occurs to the ultimate resolution of the case. Many important research questions have not been addressed, and recent changes in forensic science (most notably increased DNA testing capacity and database maturation) suggest that past studies could usefully be updated.

We therefore conducted an empirical study of the production and use of forensic evidence in five jurisdictions across the United States with different models of forensic labs and needs. The study included qualitative interviews with police, prosecutors, and crime lab personnel; the collection and analysis of a random sample of approximately 1000 crimes reported in each jurisdiction. We complemented this study with an analysis of existing national crime lab data and an experimental survey of prosecutors and defense counsel to estimate the incremental effect of forensic evidence on the plea-bargaining process.

We found that even after recent efforts at expanding lab facilities, forensic evidence is still rarely analyzed prior to arrest and charging. Instead it is often used more to strengthen existing cases and meet juror expectations than as a tool to identify suspects or confirm guilt. This is partly a function of the political economy of forensic testing, in which cases that are going to trial are prioritized over cases that are under investigation. The case disposition probabilities associated with different categories of forensic evidence testing varied substantially, but was often not significant. Our interpretation of this finding is that forensic testing is often more a symptom of a strong case rather than an independent cause of a strong case. We also found that collection and use of forensic evidence varied widely across jurisdictions. Our plea-bargaining study showed that forensic evidence has a significant effect on attorneys' perception

[12] Executive Office of the President: President's Council of Advisors on Science and Technology, FORENSIC SCIENCE IN CRIMINAL COURTS: ENSURING SCIENTIFIC VALIDITY OF FEATURE-COMPARISON METHODS (2016).

[13] Michael J. Saks and Jonathan J. Koehler, *The Coming Paradigm Shift in Forensic Identification Science* 309 SCIENCE 892, 893 (2005) (noting "cultural differences between normal science and forensic science. In normal science, academically gifted students receive four or more years of doctoral training where much of the socialization into the culture of science takes place. This culture emphasizes methodological rigor, openness, and cautious interpretation of data. In forensic science, 96% of positions are held by persons with bachelor's degrees (or less), 3 percent master's degrees, and 1 percent PhDs. When individuals who are not steeped in the culture of science work in an adversarial, crime-fighting culture, there is a substantial risk that a different set of norms will prevail.")

[14] Radley Balko and Roger Koppl, *C.S.Oy*, SLATE, August 12, 2008.

of the strength of the case and likelihood of accepting a plea bargain. We also found that the use of an information management system and fee-based laboratory funding are associated with increased clearance rates, which suggest that using information technology and a pricing system to prioritize forensic testing may reduce lab backlogs.

The Article is organized as follows. After a short review of the existing literature, we summarize our methodology and present our principal findings. After discussing these findings, we conclude with the policy implications.

I. PAST EMPIRICAL RESEARCH ON THE USE OF FORENSIC SCIENCE

Since at least the late 19th century, courts have recognized the theoretical advantages of scientific testimony. Jennifer Mnookin noted the late 19th century belief that "scientific expert testimony *should have been able to be a more reliable form of evidence*, a more authoritative method for adducing knowledge than the other means available in court."[15]

However, the available research notes how infrequently forensic evidence was utilized. In 1963, Parker, for example, noted that scientific evidence was used in less than 1% of cases.[16] Similarly, RAND's 1975 study (by Greenwood et al.) found that forensic evidence had little role in the criminal justice system despite the fact that physical evidence of some kind was available in most cases, and fingerprint evidence in more than half.[17] More recently, Peterson et al. found that, apart from homicide and rape, collection and testing of forensic evidence was rare.[18] The study also noted that forensic science was used more often once a suspect had been identified rather than as a tool at the investigative stage.[19]

And, when forensic evidence was used, its impact was unclear. Baskin and Sommers examined the effect of forensic evidence on homicide case outcomes[20]

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[15] Mnookin, *supra* note 3 at 110 italics in original.

[16] B. Parker, *The Status of Forensic Science in the Administration of Criminal Justice* 32 Revista Juridica de la Universidad P.R. 405 (1963); see also Brian Parker and Joseph Peterson PHYSICAL EVIDENCE UTILIZATION IN THE ADMINISTRATION OF CRIMINAL JUSTICE (1972) (finding limited use of forensic evidence testing).

[17] PETER GREENWOOD ET AL., THE CRIMINAL INVESTIGATION PROCESS, VOLUME III: OBSERVATIONS AND ANALYSIS (RAND: 1975).

[18] Peterson et al, *supra* note 15.

[19] The study was limited by the fact that all of the cases they gathered data on occurred prior to 2005, and by the fact that they were limited to four jurisdictions in Indiana and Los Angeles. As they noted, "This research should be replicated and refined in other jurisdictions around the nation. In particular, studies should expand and strengthen their qualitative components as they assess decision processes at important criminal justice decision levels;" Peterson, *supra* note 15, at. 9; *see also* MALCOLM RAMSAY, THE EFFECTIVENESS OF THE FORENSIC SCIENCE SERVICE (1987) (making same finding with respect to fact that forensic testing occurs after suspect identified).

[20] D. Baskin & I Sommers, *The Influence of Forensic Evidence on the Case Outcomes of Homicide Incidents* 38 J. of Crim. Just. 1141-1149 (2010).

and found no effect on the likelihood of arrest or subsequent judicial outcomes. Keel, Jarvis and Muirhead[21] and Wellford and Cronin[22] also concluded that forensic evidence had only a marginal effect on case disposition.[23]

Earlier studies seemed to find more of an effect. Forst et al.[24] found that post-arrest, "tangible evidence" gathered during the investigation predicted convictions.[25] Similarly, an archival analysis of actual criminal cases found that the probability of trial (versus a plea agreement) increased with the availability of expert testimony, which in this study included expert testimony on analyses from ballistic reports, etc.[26] These studies provide little information, however, about exactly when, how, and why types of forensic evidence influence the adjudication process.

Peterson, Mihajlovic, and Gilliland[27] compared a random selection of cases across several jurisdictions that used forensic evidence to similar cases that did not contain forensic evidence. They found that after controlling for a number of other variables, the cases that contained forensic evidence were closed three times more often than cases that did not include forensic evidence. In another study, Peterson et al.[28] found that cases containing strong forensic evidence against the accused resulted in fewer plea bargain offers by the prosecution.[29] In contrast, if the case went to trial, forensic evidence had the most influence when evidence against the defendant was weak. Forensic evidence in trial outcomes, however, was significantly less influential than other types of trial evidence.[30]

Most recently, Peterson, Sommers, Baskin, & Johnson[31] tracked the collection and use of forensic evidence in the state of Indiana and the County of Los Angeles. The influence of forensic evidence depended on the crime

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[21] Timothy Keel et al, *An Exploratory Analysis of Factors Affecting Homicide Investigations: Examining the Dynamics of Murder Clearance Rates*, 13 HOMICIDE STUDIES 50 (2008).
[22] Charles Welford & James Cronin, *Clearing up Homicide Clearance Rates*, NATIONAL INSTITUTE OF JUSTICE JOURNAL (2000).
[23] Several earlier studies attempted to model the effect of evidence on case outcomes. JAMES EINSTEIN & HERBERT JACOB, FELONY JUSTICE: AN ORGANIZATIONAL ANALYSIS OF CRIMINAL COURTS (1977) (finding found that the stronger the evidence, the higher the chance of conviction and longer the sentence, but not separately noting forensic evidence); see also Floyd Feeney, Forrest Dill, and Adrianne W. Weir ARRESTS WITHOUT CONVICTION: HOW OFTEN THEY OCCUR AND WHY, National Institute of Justice, 1983 (reaching similar conclusions).
[24] BRIAN FORST ET AL., WHAT HAPPENS AFTER ARREST?: A COURT PERSPECTIVE OF POLICE OPERATIONS IN THE DISTRICT OF COLUMBIA (1977).
[25] The operational definition of "tangible evidence" in this study, however, was not clearly defined.
[26] Martha Myers & John Hagan, *Private and Public Trouble: Prosecutors and the Allocation of Court Resources* 26 SOCIAL PROBLEMS 439 (1979).
[27] JOSEPH PETERSON ET AL., FORENSIC EVIDENCE AND THE POLICE: THE EFFECTS OF SCIENTIFIC EVIDENCE ON CRIMINAL INVESTIGATIONS (1984).
[28] Joseph Peterson et al., The Uses and Effects of Forensic Science in the Adjudication of Felony Cases, 32 J. of Forensic Sciences 1730 (1987).
[29] Peterson, *supra* note 28
[30] Peterson, *supra* note 28
[31] Peterson, *supra* note 15

examined. For example, in aggravated assault cases, forensic evidence was not a significant predictor of plea bargaining decisions. Plea bargaining rates in homicide cases with forensic evidence were similar to rates in homicide cases with no forensic evidence. However, certain types of forensic evidence, specifically biological evidence, latent prints, and firearms evidence, were present more often in homicide cases that went to trial than cases that were pled out. In contrast, robbery cases containing forensic evidence were more likely to plead out (68%) than robbery cases that did not contain forensic evidence (36%). Plea bargaining rates in burglary cases were too high (95%) to identify differences based on forensic evidence.[32]

Other research[33] has specifically examined the influence of DNA evidence on case outcomes by comparing outcomes in a sample of sexual offense cases containing DNA evidence to a matched sample of cases that did not contain DNA evidence. While the presence of DNA evidence was a significant predictor of guilty verdicts at trial, DNA evidence did not predict guilty pleas.[34] Briody's research examining the influence of DNA on case outcomes in homicides produced similar findings.[35] More recently, Shawn Bushway, Allison Redlich, and Robert Norris tested the "shadow of the trial" theory of plea bargaining by distributing varying hypothetical case files to prosecutors, defense counsel, and judges. This permitted them to measure the effect of DNA and other kinds of non-forensic evidence on the outcome of plea bargaining.[36]

Although these studies have broken important ground, the lack of consistent findings in the literature leaves many questions as to how forensic evidence influences case outcomes. Moreover, the most recent analysis of cases containing forensic evidence[37] examined cases that originated in 2003 and 2005, prior to the recent expansion in lab capacity and new attention being paid to forensic science. In short, many important research questions have not been addressed, and recent changes in forensic science (including increased DNA testing capacity) suggests that past studies could usefully be updated.

II. RESEARCH QUESTIONS AND METHODOLOGY

The report is structured around the following research questions:

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[32] Peterson, *supra* note 15.
[33] Michael Briody, *The Effects of DNA Evidence on Sexual Offence Cases in Court*, 14 CURRENT ISSUES IN CRIMINAL JUSTICE 159 (2002).
[34] Briody, *supra* note 33.
[35] Michael Briody, The Effects of DNA Evidence of the Criminal Justice Process (2004) (unpublished Ph.D. dissertation, Griffeth University).
[36] Shawn D. Bushway, Allison D. Redlich & Robert J. Morris, *An Explicit Test of Plea Bargaining in the "Shadow of the Trial"* 52 CRIMINOLOGY 723 (2014).
[37] Peterson, *supra* note 15.

1. *What is the perceived utility of forensic analysis? How often is forensic evidence collected, how often is it analyzed, and when is it analyzed?*
2. *What are the outcomes of forensic evidence testing? How often does forensic evidence testing yield useful information?*
3. *What is the correlation between forensic evidence testing, arrest, and charging decisions?*
4. *What is the correlation between forensic evidence testing and the plea-bargaining process?*
5. *What is the correlation between forensic evidence and conviction?*
6. *Are concerns about forensic testing turnaround time warranted?*
7. *What is the correlation between the institutional configuration of crime laboratories and their productivity?*

To answer these questions we conducted four related empirical studies: (1) In five widely varying jurisdictions, we analyzed data on a random sample of 1000 reported crimes to measure the association between forensic evidence and criminal justice outcomes; (2) in those same jurisdictions, we interviewed police, forensic lab personnel, and prosecutors; (3) we conducted an experimental survey of prosecutors and defense counsel, and (4) we used the national census of crime labs to test hypotheses about crime laboratory institutional configuration.

Study Sites

We collaborated with agencies in Sacramento County, CA, Sedgwick County, KS, Allegheny County, PA, Bexar County, TX, and King County, WA as our sites for data collection and interviews. These were desirable sites for several reasons: 1) the sites reflect some of the diversity found in institutional configurations of the crime labs in the criminal justice system; 2) two of the sites are jurisdictions which participate in the National Incident-Based Reporting System (NIBRS), which facilitates collection detailed offense-level information for these jurisdictions; 3) the sites represent a range of law enforcement agencies in size and geographic diversity; 4) the jurisdictions have adopted a variety of policies to prioritize testing. This variation will assist us in better understanding the wide range of issues raised in the production, testing and use of forensic evidence.

Sacramento County, CA. Sacramento County is one of three California counties whose crime laboratory is under the authority of the District Attorney's

Office.[38] We recruited the Sacramento County District Attorney's and its crime lab, along with the Sacramento Police Department, partly to see if any novel issues arise with respect to analysis and use of forensic evidence under this institutional crime laboratory arrangement.

Sedgwick County, KS. The Sedgwick County Regional Forensic Science Center (SCRFSC) includes both the crime laboratory and the medical examiner's office. Located in the county seat of Wichita, the SCRFSC receives the majority of its submissions from the Wichita Police Department.

Allegheny County, PA. In Allegheny County the crime lab is housed within the Medical Examiner's Office. Its county seat, Pittsburgh, is the second-largest city in the state. Both the Pittsburgh Bureau of Police and the Allegheny County District Attorney's Office participated in the study.

King County, WA. Forensic analysis throughout the state of Washington is provided by a network of laboratories under the control of the Washington State Patrol, which is primarily responsible for policing the highways. Far from typifying the law enforcement crime laboratory institutional configuration, the situation in Washington is unusual because the law enforcement agency that oversees the laboratory rarely has need for its services. We enlisted the participation of the main laboratory in King County for interviews and case data, as well as the Seattle Police Department and the King County Prosecutor's office.

Bexar County, TX. The Bexar County Criminal Investigation Laboratory (BCCIL) is an independent, standalone laboratory. Approximately 60 percent of its work comes from San Antonio Police Department. BCCIL is quite unusual in that it has operated on a fee-for-service model since 1997.[39] The method public sector crime labs typically use for prioritizing cases are submission policies, which restrict the types of cases the lab will consider and the number of samples/case.[40]

Table 1 summarizes the population size, crime rates (incidence per 100,000 residents) and police force strength for the five cities over the study period of 2006-2009.

Table 1. Population, Police Force Strength, and Crime Rates (per 100K) for Study Law Enforcement Agencies

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[38] Santa Clara County and Solano County are the other two. The Orange County Crime Lab is, according to its website, "administered through a cooperative partnership of the Sheriff-Coroner, the District Attorney, and [the County CEO]."

[39] Personal communication, BCCIL Laboratory Director Tim Fallon

[40] In theory this system mitigates overuse of the crime lab because the users do not directly bear the costs of its utilization. The fee-for-service system shifts the costs to the submitting agencies on the principle that budget constraints will lead to more frugal use of crime lab services. Submission policies can be seen as a regulatory approach to controlling demand, while fee-for-service is a market-based solution where the supply of services meets demand at cost.

	Average Population[a]	Police Force Strength[b]	Homicide	Rape	Robbery	Aggravated Assault	Burglary
Pittsburgh[c]	312,349	868	0.18	0.39	4.83	5.11	10.52
Sacramento[d]	458,283	801	0.10	0.40	4.13	6.02	11.97
San Antonio[e]	1,334,750	1795	0.09	0.41	1.91	3.75	12.82
Seattle[f]	598,771	1277	0.04	0.19	2.75	3.33	11.15
Wichita[g]	363,878	646	0.08	0.72	1.43	6.73	11.18

[a] U.S. Census Bureau QuickFacts (https://www.census.gov/quickfacts/)
[b] Law Enforcement Management and Administrative Statistics (2007).
[c] Pittsburgh Police Department Annual Reports for 2007 (http://cprbpgh.org/966) and 2009 (http://www.pittsburghpa.gov/police/files/annual_reports/09_Police_Annual_Report.pdf)
[d] Sacramento Police Department annual reports (http://www.cityofsacramento.org/Police/About-SPD/Annual-Report)
[e] Texas Crime Reports (http://dps.texas.gov/administration/crime_records/pages/crimestatistics.htm)
[f] Washington Association of Sheriffs and Police Chiefs Crime Statistics Reports (http://www.waspc.org/crime-in-wa-archive-folder)
[g] Kansas Bureau of Investigation Crime Statistics Reports (http://www.accesskansas.org/kbi/stats/stats_crime.shtml)

I *Quantitative Analysis of Random Sample of Felony Cases*

1. Data Collection

To examine how forensic evidence is correlated with criminal justice outcomes, we obtained data on samples of homicide, sexual assault, aggravated assault, robbery, and burglary cases from each of the five study jurisdictions.[41] In selecting our sampling frame, we sought to balance competing goals of looking at fairly recent crimes with the problem of right-censoring due to protracted investigation and adjudication phases often characteristic of serious felonies.[42] Ultimately, we opted to collect a random sample of 200 crimes of forcible rape, aggravated assault, robbery, and burglary, generated from each law enforcement agency's comprehensive listing of reported crimes that occurred between 2007 and 2009. Because homicide is (fortunately) a less common event, we requested data on every recorded murder over the three-year period for all the sites except San Antonio, by far the most populous of the five jurisdictions in our study. In all five jurisdictions we added calendar year 2006 to increase the homicide sample size and the number of fully adjudicated cases, but were still shy of 1000 homicides total.

Three codebooks were distributed to guide law enforcement agencies, crime laboratories, and prosecutors' offices in the collection of this data, along with

[41] We followed the Uniform Crime Reports classification system of making sure the crime in question was the most serious crime where more than one crime was committed in the incident.
[42] We also had to compromise between the desire for statistical power to test the impact of numerous variables with the labor required, both on our part and on the part of participating agencies, to assemble and code large data sets, sometimes from paper records.

corresponding spreadsheets listing the randomly selected case numbers as rows and the variable names as column headers. The Offense Codebook for law enforcement agencies was largely based on the National Incident-Based Reporting System (NIBRS) data dictionary in order to facilitate data collection for NIBRS-participating police departments (Seattle PD and Wichita PD). Not surprisingly, Records Management Systems for non-NIBRS agencies contained many of the same fields (e.g. offense date, arrest date, suspect and victim characteristics). In addition, the Offense Codebook also asked agencies whether and what types of forensic evidence were collected in the course of the investigation.

Crime laboratories received a Forensic Variable Codebook which began with two yes/no questions- whether any forensic evidence was submitted for analysis, and whether any forensic evidence was actually analyzed- followed by a series of items to detail what types of analysis were conducted and what results were obtained, as well as dates of analysis request, completion, and database outcomes.[43] Finally, prosecutors were given a Judicial Outcomes Codebook to record, for those cases in which a suspect was arrested, how and when the cases progressed through the criminal courts.[44]

There are important limitations in the information we were able to obtain from the study sites. For Allegheny County, we lack specific information on what types of evidence were collected by the police, apart from what can be inferred from those cases with submissions to the crime laboratory. For Sedgwick County, data on types of evidence is incomplete, with numerous items categorized only as "miscellaneous." Sacramento County and King County were unable to provide information on which cases were accompanied by witness reports. At all of the sites, fingerprint examinations were conducted by law enforcement agencies, but records were only accessible from Sacramento and King Counties. Toxicology laboratories were similarly distinct from other crime laboratory functions, with their own management and case records, so we only received data on toxicology analyses from Allegheny, Sacramento, and Sedgwick County. Allegheny County crime lab was unable to provide data on which cases had DNA profiles uploaded to the Combined DNA Index System (CODIS) database and whether any had yielded matches. Table 2 summarizes the differences in data across study jurisdictions.

Table 2: Data availability by county

	Allegheny	**Bexar**	**King**	**Sacramento**	**Sedgwick**
Forensic Evidence Collected	N	Y	Y	Y	Y
Witness Reports	Y	Y	N	N	N

[46]We had hoped most of the crime lab case variables could be gleaned electronically from laboratory information management systems, but all five labs had to resort to paper records to complete our data request, increasing the time and expense of data collection.
[44] Codebooks are available upon request from the authors.

Fingerprint Comparison	N	N	Y	Y	N
Toxicology Analysis	Y	N	N	Y	Y
CODIS Entry/Result	N	Y	Y	Y	Y

Table 3 below shows the distribution of the sample of crimes over crime types, for each of the five counties in the data. Including all homicides over a four-year span in the sample for each jurisdiction, the total was less than 200 in all but Bexar County. Sample sizes for some other offense categories were less than 200 because of misclassification- other, typically less serious offenses erroneously made their way into the sample.[45]

Table 3: Number of crimes by crime type and county

	Sedgwick	Bexar	Sacramento	Allegheny	King	Total
Murder	138	201	163	197	91	**790**
Rape	198	0[46]	201	199	200	**798**
Aggravated Assault	198	177	200	186	200	**961**
Robbery	199	187	200	199	200	**985**
Burglary	198	174	200	197	174	**943**
Total	**931**	**739**	**964**	**978**	**865**	**4477**

2. Methodology

Our objective was to investigate whether and to what extent the collection and analysis of forensic evidence is correlated with criminal justice outcomes.

An important consideration at the outset is defining the unit of analysis. Prior to arrest, the natural unit of analysis is the reported crime. However, once one or more arrests have been made, the term "case" may refer to the legal cases against one or more arrestees. This complicates the analysis since each *crime* may result in multiple *judicial cases*[47] which may lead to different outcomes for each arrestee. However, we lack information about the outcomes of the forensic

[45] Burglaries were the most error-prone offense category, at 13 percent. Given the already labor intensive data collection process, we opted not to ask participating law enforcement agencies to generate new random samples.

[46] In San Antonio we encountered a different problem with the case sample, which was inadvertently drawn from all manner of sexual assaults, not just forcible rape, with the result that very few cases in the random sample actually were forcible rapes. The forcible rape offense category was thus dropped from the San Antonio sample.

[47] Confusingly, the term "case" can refer to both a reported crime (as it might be used by investigating detectives in referring to "unsolved case") as well as a legal case against a specific defendant.

analysis with respect to each arrestee. In order to maintain a consistent sample definition throughout, we use the *reported crime* as our unit of analysis and refer to each as a case. In the relatively rare circumstance in which there is more than one arrestee, and therefore more than one judicial outcome, we collapse the multiple observations as follows: For charging, plea and trial decisions, and conviction, we consider each of these outcomes to have occurred if any of the arrestees experienced that outcome, e.g. a case is considered to have resulted in a conviction if any of the arrestees was convicted. When we look at the outcome of sentence length, we consider the maximum sentence length handed down to any of the defendants. We follow a similar procedure when constructing case characteristics: We code whether any of the victims was white or female, and whether any of the arrestees was white or female.

Our basic methodology is to use regression analysis to isolate the correlation of forensic analysis with outcomes ranging from arrest to conviction, while controlling for observable case characteristics. Although different types of evidence may be predictive of outcomes for different types of crime,[48] we conduct an analysis that pools different offenses for reasons of statistical power.

We are particularly interested in associations between forensic analysis and the probability that a case progresses from one stage to the next in the criminal justice system. For instance, a certain type of forensic testing may be useful in identifying suspects prior to arrest, but may have little bearing on outcomes later in the process, at which point other kinds of analysis may be more predictive of the outcome. We are therefore interested in modeling conditional probabilities, i.e. at each stage, we examine how the various types of forensic testing predict the outcome, *conditional on the case having progressed to that stage*. We postpone to the analysis a discussion of the various econometric issues that arise in this unique context.

We should, at this point, emphasize that our analysis does not presume that progression of a particular case to trial and/or conviction is necessarily optimal or desirable–indeed, one may argue that the value of forensic evidence in exonerating innocent individuals is greater than its value in obtaining convictions. Because we collected information on the results of forensic analysis, we can, to an extent limited by the size of our sample, distinguish between the effects of exculpatory and inculpatory evidence, and thereby test whether forensic evidence is contributing to making the outcomes more "just", as opposed to simply helping law enforcement agencies to prosecute individuals.

Interviews

We conducted semi-structured interviews with detectives, prosecutors, and crime laboratory management working at participating agencies to gain insight

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[48] See Peterson, *supra* n. 4

into how forensic evidence is used.[49] With the exception of one agency (one prosecutor's office declined to participate), we interviewed at least five key informants from each of the participating agencies (police department, prosecutor's office, and crime laboratory) involved in the provision and use of analyzed forensic evidence at each of the five sites. Each semi-structured interview lasted approximately one hour. Interviews across agency type did address several common themes, including respondents' perceptions of the advantages and disadvantages of the crime lab's institutional setting; the prioritization of cases to determine if and when there might be conflict over limited laboratory resources; the extent of cooperation that occurs between the agencies; impediments to better cooperation; and overall satisfaction with the provision of forensic evidence analysis and the system for its delivery. To protect the confidentiality of participants, respondents are referred to by generic job title (i.e., detective, prosecutor, crime laboratory analyst or manager).

Separate interview instruments were devised for detectives, prosecutors, and forensic scientists. In general, detectives were asked about the use of forensic evidence in their investigations, including what determines whether a crime scene investigation is conducted, who collects evidence at crime scenes, and how forensic evidence has assisted or impeded investigations. Forensic scientists were asked questions about meeting evidence analysis demands and challenges to maintaining scientific objectivity within an adversarial system. Prosecutors were asked questions about the use of forensic evidence in the adjudication process, including whether forensic evidence was commonly tested before entering plea negotiations, how forensic evidence results influence plea bargaining negotiations, and jurors' knowledge and expectations of forensic evidence.

We made a point of interviewing personnel with considerable relevant experience. Within the five police departments, we arranged to interview detectives and supervisors assigned to units that handled each of the five crimes of interest in this study: homicide, sexual assault, aggravated assault, burglary, and robbery. Within forensic laboratories, we sought out scientists and/or supervisors involved with analysis of different types of forensic evidence examined in this project including: DNA; firearms; trace; and narcotics. At county prosecutor offices, most of our interviews were with attorneys who had extensive experience handling serious felony cases.

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[49] We chose to conduct semi-structured interviews instead of structured interviews because the semi-structured format permitted open-ended questions and follow-up questions, allowing interview subjects to stray from the prepared list of topics. This flexibility provided an opportunity for the participants to express insights that a more circumscribed interview format might miss.

Attorney Experimental Survey

The third part of the study involved an experimental study with practicing prosecutors and defense attorneys across the country.[50] The goal of this portion of the study was to better understand the effects of forensic evidence on case outcomes related to attorney decision-making. We presented attorneys with a hypothetical robbery case[51] in which we manipulated whether the case featured individualizing forensic evidence (DNA evidence), and associative forensic evidence (glass fragments).[52] Within the individualizing condition, we further manipulated whether the DNA testing resulted in a highly individualized finding in which there was a very low probability that another person contributed the sample, or a more ambiguous finding.[53] After viewing the hypothetical case file, participating attorneys estimated their likelihood of offering or accepting a plea

[50] Attorneys were recruited from a database of contact information for District Attorneys and Public Defenders that was compiled through on-line searches for practicing attorneys in approximately 25 states. This database includes attorneys practicing in a wide variety of geographical locations, jurisdictional sizes, etc. Attorneys were recruited to participate in the online study via email. The solicitation email provided a brief description of the study, an electronic link to the survey, and a random ID number for the attorneys to enter on the consent page of the study. Responses from 56 prosecuting attorneys and 55 defense attorneys are examined in the present analysis. The survey instrument is available upon request from the authors. For a similar method, *see* Shawn D. Bushway, Allison D. Redlich & Robert J. Morris, *An Explicit Test of Plea Bargaining in the "Shadow of the Trial"* 52 CRIMINOLOGY 723 (2014).
[51] Attorneys were instructed to assume the role of prosecutor or defense attorney, depending on their positions. The case file contained a police form describing the victim's statements concerning the robbery, information that the defendant had refused to be interviewed by the police, and information about a lineup that was conducted in which the victim identified the defendant in a photo lineup. The file also included a description of the forensic evidence collected in the case and a report by the forensic lab describing the evidence analyzed and analysis results.
[52] In the individualizing condition, the case file contained a description of blood evidence that was collected from a display case broken during the commission of the robbery. The blood sample and a sample taken from the defendant were subsequently submitted for DNA testing. The DNA evidence was either ruled a complete match or a partial match in the forensic lab report. In the associative evidence condition, the file contained a description of glass that was collected from a display case broken during the commission of the robbery, and broken glass that was collected from the sleeve of the sweatshirt of the defendant upon his arrest. Glass collected from the crime scene and the defendant's sweatshirt was submitted to the forensic lab for testing and in the forensic report was described as consistent.
[53] Specifically, the study employed a 2 (Prosecution vs. Defense) x 3 (Forensic evidence type: Associative vs. Individualizing, Match vs. Individualizing, Partial March) factorial design. The case file contained a police form describing the victim's statements concerning the robbery, information that the defendant had refused to be interviewed by the police, and information about a lineup that was conducted in which the victim identified the defendant in a photo lineup. The file included a description of the forensic evidence collected in the case and a report by the forensic lab describing the evidence analyzed and analysis results. In the police report and forensic lab report, we manipulated the type of forensic evidence collected and analysis results.

bargain and the importance of the forensic evidence in their decision-making process.[54]

The hypothetical scenarios only manipulated factors related to forensic evidence, allowing us to isolate the effects of forensic evidence on attorneys' decisions and lending insight into how the type and probative value of forensic evidence influence attorneys' plea-bargaining decisions.

Analysis of National Crime Lab Census Data

Finally, we performed an analysis using national data to investigate how structural and institutional factors might influence the efficiency of forensic laboratories. The Bureau of Justice Statistics' "Census of Publicly Funded Crime Laboratories" is a survey periodically administered to gather information about laboratory budget, staffing, output, and backlog.[55]

The Census of Forensic Labs was conducted in 2002, 2005 and 2009. The surveys elicited information from forensic labs across the country on organizational structure, jurisdiction served, types of services provided, and the number of requests received and completed in each category of forensic analysis. The granularity of these categories improved over survey years. To construct a consistent dataset, we retained only the categories defined in the first year of the data, 2002. These categories are: (1) Firearms/Toolmarks, (2) Trace evidence, (3) Latent prints, (4) Controlled substances, (5) Toxicology, (6) Questioned documents, (7) Computer crimes, (8) Crime scene, (9) Biology screening, (10) DNA analysis, (11) Other services.

Since our analysis focuses on violent offenses, we restricted attention to a smaller set of categories: Firearms/Toolmarks, Trace evidence, Latent prints, Crime scene, Biology screening and DNA analysis. The data record the number of requests for analysis that were processed by the lab during the calendar year. To convert this information to a rate, we divide it by the number of requests received during the year plus the number of backlogged requests as of the beginning of the year. About 93% of the counties represented in these data have only one crime lab. In all remaining cases, we average the data to measure lab

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[54] Participants were asked to rate the likelihood that the case would go to trial. Prosecutors were asked about the likelihood they would offer a plea bargain of five, three, or one year in prison in exchange for a guilty plea in the case. Following each likelihood ratings, prosecutors were asked to provide reasons why they would or would not offer each plea deal. Defense attorneys were provided with the same series of plea bargain offers. For each offer, the defense attorney rated the likelihood that they would recommend that their client accept the offer and provide a reason for their recommendation. Attorneys rated the strength of their case and the likelihood they would win the case if it were to go to trial on seven-point likert scales.

[55] Bureau of Justice Statistics, Census of Publicly Funded Forenisc Crime Laboratories (2009), available at http://www.bjs.gov/index.cfm?ty=dcdetail&iid=244, last checked September 21, 2015.

clearance rates at the level of the county. We further restrict the sample to counties that appear in all three years of the data.

We use regression analysis to shed light on the determinants of lab clearance rates, relating the latter to factors such as the laboratory's operating budget, the number of personnel, and its funding structure.

III. RESULTS

We structure our discussion of the results to follow our research questions.

What is the perceived utility of forensic analysis? How often is forensic evidence collected, how often is it analyzed, and when is it analyzed?

From reports of long backlogs and overwhelmed crime laboratories, one might conclude that forensic evidence analysis is a feature of virtually every criminal investigation. The reality, at least for our study sites, was quite different. Table 4 provides estimates for the fraction of cases that had forensic evidence collected and analyzed.[56]

Table 4. Collection and Analysis of Forensic Evidence by Site and Offense Category (percentage and 95% confidence interval)

Site	Homicide		Forcible Rape		Aggravated Assault		Robbery		Burglary	
	Evidence Collected	Evidence Analyzed	Evidence Collected	Evidence Analyzed	Evidence Collected	Evidence Analyzed	Evidence Collected	Evidence Analyzed	Evidence Collected	Evidence Analyzed
Sacramento	96.2±2.4	87.1±7.3	91.8±3.4	74.5±13.2	52.4 ±4.8	9.4±1.2	54.5±2.5	3.5±0.5	30.0±7.8	0.4±0.6
San Antonio	95.8±2.7	84.4±9.5	-----	-----	43.5±16.1	10.7±3.3	15.0±5.8	0.5±0.9	4.6±1.5	0.6±0.9
Seattle	89.6±4.5	17.1±13.8	60.1±4.0	8.7±3.3	17.4±6.3	0.9±0.9	13.4±0.6	0.7±1.3	18.5±4.3	1.2±1.2
Wichita	80.4±6.7	65.9±6.3	81.9±9.1	30.2±4.0	80.7±5.8	6.0±2.1	51.0±7.9	3.3±2.3	37.9±11.6	1.1±1.0

Considerable variation is seen both across sites and across offense categories. First, the variation in the collection of evidence among sites is remarkable. While forensic evidence was collected in 80 percent or more of murder cases investigated by all four police departments for which we had data, the remaining four offense categories exhibit significant disparities in the frequency of forensic evidence collection. Seattle PD collected forensic evidence in only about 60

[56] No data was available on evidence collection from the Pittsburgh police. The forcible rape offense category was excluded from San Antonio for this and all further analysis because of the problem with the sample containing mostly cases of child molestation and other forms of sexual assault.

percent of forcible rape cases in the sample, whereas Sacramento PD collected forensic evidence in over 90 percent of its forcible rape cases.

Differences are observed in the rates at which collected evidence was analyzed as well. The fraction of cases in which forensic evidence is *analyzed* in murders varies dramatically from a high of 87 percent for cases in Sacramento to a low of 17 percent for cases in Seattle. These disparities attest to the degree of decentralization in our criminal justice system, as there appears to be little standardized practice, even in large jurisdictions in murder cases. However, it is important to bear in mind that our study did not capture all forensic evidence at all sites, nor did it capture testimonial evidence or physical evidence related to the autopsy at any site.

Moving from murder to burglary, the rate of analysis, conditional on evidence collection, declines.[57] The use of forensic evidence in burglary and robbery cases is consistently low (despite research that suggests it can be effective).[58] Analysis rates for robberies were less than five percent and analysis rates for burglaries were 2 percent or less at all sites, though we do not observe fingerprint analysis in San Antonio and Wichita.

These findings align with statements of interviewees. Across jurisdictions, homicide detectives reported that forensic evidence was almost always collected at murder scenes or in the ensuing investigation. Detectives tasked with investigating aggravated assaults, robberies, or burglaries, however, acknowledged that many of their cases have no forensic evidence. Because sexual assaults are sometimes reported well after the crime commission, forensic evidence is sometimes not present in rape cases, either. Resource constraints are also a factor, with homicides receiving the lion's share of investigative resources. Because of the relative rarity and severity of murder, homicide detectives, with few exceptions begin investigating cases at the crime scene. Other crimes against persons, however, are typically assigned to detectives by a supervisor the next day (or the following Monday for weekend incidents). Usually the scene is processed by patrol officers, in consultation with the patrol sergeant at the station, who has to be budget conscious and may not have investigational experience. When asked how he usually becomes involved in a case, a detective assigned to crimes against persons answered:

> *It really depends on how serious it is. On the really serious stuff you're going to be made aware of it in daily summaries, but if it's a garden-variety street robbery with no injuries it might be 2-3 days before it's assigned. It depends also on the number of cases in the queue and peoples' schedules. We still do have on-call…I used to get called out a lot more frequently. They've really changed it for our unit, to save money.*

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[57] Relative to the other three departments, the drop off in forensic evidence collection for robberies and burglaries is less steep in Wichita, but forensic evidence collection was broadly defined in Wichita.

[58] Roman, *supra* note 3.

Although burglary detectives indicated that forensic evidence was infrequently used, several recalled cases in which key forensic evidence was left behind at the scene, for example cigarette butts in houses where no one smoked, or blood around a broken window at the point of entry. One burglary detective voiced a desire to see more time and resources devoted to processing burglary crime scenes, particularly given the high rate of repeat burglary offenders.

Detective responses were also consistent with observed patterns for submitting collected evidence to the crime lab. Homicide detectives reported routinely requesting evidence examinations and tests from the crime lab. Detectives in sexual assault units generally described crime lab use as somewhat less frequent, pointing out that even when forensic evidence is present, it may be of limited value if consent rather than identity is at issue. Robbery and burglary detectives varied between jurisdictions and in some cases reported using the lab as few as 3 or 4 times per year.

When asked about the importance of forensic evidence in their pre-arrest investigations, the most frequently mentioned benefits were: (1) confirming suspicions and bolstering probable cause for arrest; (2) ruling out scenarios or suspects so investigations can proceed more efficiently; (3) using potential forensic evidence as leverage for obtaining confessions, even if the evidence has not been analyzed at the time of interrogation, or even if no such evidence actually exists; (4) reviving a cold case by providing, through a database match, the name of a putative perpetrator or link to another unsolved crime, and; (5) increasing the likelihood the case will eventually be adjudicated through plea agreement, thus reducing the amount of time detectives spend in court. DNA, firearms, and fingerprints were mentioned most often by detectives as being key pieces of forensic evidence.

Some detectives, particularly those investigating property crimes or crimes in which the suspect's identity is typically not in doubt, saw less utility in forensic evidence. These detectives stressed that forensics is just one piece of the puzzle. As one crime investigator remarked, "It is not possible to go to court with only forensic evidence." Several detectives made it clear they do not do anything differently when they have forensic evidence. Rather, they "work the case", interviewing witnesses, checking alibis, and following leads regardless of whether crime laboratory analysis of evidence has anything to contribute. The fact that available forensic evidence did not affect the detectives' approaches to the case suggests that changing the practice of police may be necessary to fully realize the potential of forensic evidence.

Finally, although some detectives recalled cases in which forensic evidence testing complicated or contradicted their theory of the crime, none of them saw this as a drawback. Instead, they felt that it forced them to re-examine their thinking or prevented them from continuing to pursue the wrong suspect. As one Sacramento PD detective put it, "You can get stuck trying to make the crime fit your scenario. We had a murder suspect with blood on his shoes who lived in the same apartment complex as the victim. We held him on some outstanding warrants until the lab did the analysis and told us it didn't match our victim. We went back to the drawing board and ended up with a set of facts that made more sense."[59]

Some investigators we interviewed may have expressed less enthusiasm for the utility of forensic evidence because in their experience it is usually not helpful until after an arrest has been made. We make use of the information on forensic analysis dates to examine the utilization of forensic analysis at each stage of the criminal justice process. Table 5 shows the fraction of cases in our sample for which at least one forensic analysis was requested and/or completed prior to the outcomes of arrest, plea bargain and trial, for each of these categories: (i) Trace evidence (this includes hairs, fibers, glass and paint testing), (ii) Drug analysis, (iii) DNA evidence (including STR and Y-STR testing), (iv) Firearms evidence (including test firing weapons, comparison scope examinations of bullet striations and cartridge case firing pin impressions to determine if a particular gun was used in a crime, and Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy (SEM/EDX) to identify gunshot residue on the hands, clothing, etc., (v) CODIS (DNA database entry), (vi) NIBIN (firearm toolmark database entry),; for each outcome, the sample is restricted to cases in which the outcome (i.e. arrest, plea, or trial) actually occurred. Thus, these figures represent the fraction of arrests, pleas and trials that are preceded by requests for and completion of forensic analysis. A third column lists the fraction of cases in which the completed analysis yields a probative result.

[59] Another investigator noted that "[Forensic evidence] helps you keep an open mind as an investigator. You can get stuck trying to make the crime fit your scenario."

Table 5. Rates of arrest, plea and trial outcomes that were preceded by request for and completion of forensic analysis

	Prior to arrest (N=1139)			Prior to plea bargain (N=470)			Prior to trial (N=357)		
	R[a]	C[a]	P[a]	R	C	P	R	C	P
Trace analysis	0.1%	0.0%	0.0%	1.5%	0.9%	0.0%	3.9%	2.0%	0.0%
Drug analysis	1.0%	0.4%	ND	1.3%	0.9%	ND	1.4%	0.8%	ND
DNA analysis	3.5%	2.5%	1.7%	7.0%	6.8%	6.0%	22.4%	21.8%	19.9%
Firearms /toolmark analysis	3.9%	3.2%	2.5%	9.1%	8.1%	4.2%	24.6%	23.2%	16.0%
CODIS search	2.2%	2.2%	1.4%	6.6%	6.6%	3.4%	10.6%	10.6%	1.7%
NIBIN search[b]	3.2%	3.2%	0.4%	6.2%	6.2%	1.1%	16.8%	16.8%	2.5%

[a] R= Requested, C= Completed, P= Probative

[b] The National Integrated Ballistic Information Network (NIBIN), overseen by the Bureau of Alcohol, Tobacco, Firearms, and Explosives, is a database of digital images of spent cartridges casings and bullets from crime scenes or test-fired from guns confiscated by law enforcement.

Rates of prior request increase slowly as we move from arrest to plea (in fact, the absolute number of cases with completed analysis barely changes from pre-arrest to pre-plea), with a sharp increase at the pre-trial stage, suggesting either that the prospect of trial spurs further forensic analysis or that the cases that go to trial are ones that had significantly more forensic evidence and/or analysis to start with than the ones that pled out. In any event, these rates are strikingly low throughout, and especially so at the arrest stage.[60] Trace and drug analysis are highly dependent on arrest to provide context. Hairs, fibers, paint transfers, require an exemplar from a suspect's person, vehicle, or house in order to have probative value, and such searches normally take place pursuant to probable cause for arrest. Our study didn't collect data on positive drug identification because of its ambiguous relevance to non-drug offenses.

By contrast, DNA and firearms/toolmarks analysis account for the majority of forensic analyses requested, and corresponding CODIS and NIBIN searches are carried out at relatively high rates of completion and probity, indicating their value not only to prosecutors but to detectives with no viable suspects.

Table 5 also sheds some light on the timeliness of forensic analysis. The availability of analysis appears to be reasonably responsive in the case of DNA and firearms analysis, as attested by the fact that rates of prior completion are close to rates of request, but this is less likely to be the case for drug and trace analysis.

[60] Peterson et al., also note that arrest of a suspect often precedes forensic analysis.

How often does forensic evidence testing yield useful information?

Testing of forensic evidence does not always add value to an investigation/prosecution. Even strongly exclusive or inclusive evidence is not always helpful. For example, the DNA profile from a cigarette butt on the curb of a busy street where a robbery getaway car was parked, if it excludes the suspect, may be unrelated to the crime – or it may belong to the actual perpetrator. Still, to get a sense of the distribution of forensic analysis testing and the "success rates", we tabulated how often forensic analysis results in our sample were inconclusive or conclusive (either in the direction of inclusion or exclusion) for the broad categories enumerated in Table 5, as well as for fingerprint evidence.[61]

Table 6 below summarizes the rates of forensic analysis on the basis of these categories, for each of the offense types in our data. These rates are unconditional, i.e. for each type of analysis we do not condition on whether or not evidence that could be used for such an analysis was collected.

Table 6: Rates of Occurrence and Outcome of Forensic Analyses by Crime Type (percentage)

	Murder	**Rape**	**Aggravated Assault**	**Robbery**	**Burglary**	**Total**
Trace evidence						
Analyzed	3.4	0.1	0.1	0.0	0.0	0.7
Inconclusive	0.9	0.0	0.0	0.0	0.0	0.2
Inclusion	1.1	0.0	0.0	0.0	0.0	0.2
Exclusion	1.4	0.1	0.1	0.0	0.0	0.3
Drug evidence						
Analyzed	3.4	23.2	0.9	0.6	0.6	8.7
DNA evidence						
Analyzed	19.6	10.8	1.3	1.8	.7	6.4
Inconclusive	3.4	2.3	0.0	0.1	0.1	1.1
Weak inclusion	1.4	0.4	0.2	0.1	0.0	0.4
Strong inclusion[62]	12.4	6.8	1.0	1.6	0.5	4.2
Exclusion	2.4	1.4	0.1	0.0	0.1	0.8
Firearms evidence						
Analyzed	27.3	6.5	7.5	2.4	1.1	8.5
Inconclusive	5.8	0.6	0.1	1.0	0.3	2.0

[61] Given the size of the sample, it was not feasible to estimate the effect of every single type of forensic analysis.

[62] Strong inclusions refer to biological evidence determined to originate from a single source and matching a suspect or the victim to the exclusion of virtually everyone else, as opposed to weak inclusions consisting of DNA mixtures or partial DNA profiles.

Inclusion	18.2	5.5	0.7	0.4	0.7	5.6
Exclusion	3.3	0.4	0.6	0.9	0.1	0.9
CODIS database entry						
Uploaded	12.3	7.5	0.8	1.2	0.3	3.9
No match	8.8	4.2	0.8	0.4	0.0	2.5
Inclusion	3.5	3.3	0.0	0.8	0.1	1.4
NIBIN database entry						
Uploaded	18.9	5.0	6.6	1.1	0.6	6.2
No match	14.8	3.8	5.2	0.9	0.6	5.0
Inclusion	4.1	1.2	1.4	0.2	0.0	1.3
Fingerprints evidence						
Analyzed	17.4	11.3	4.3	10.0	28.6	17.4
No match	12.9	9.5	3.8	9.0	23.5	12.9
Inclusion	4.5	1.8	1.5	1.0	5.1	4.5

Note: The figures in the table refer to the percentage of cases in which each type of analysis was performed or outcome was obtained. In the case of forensic testing outcomes (i.e. inclusion, exclusion, etc.) the percentages are unconditional, i.e. not conditional on whether forensic evidence was analyzed. In a number of cases, multiple pieces of evidence were submitted for analysis. For each such case, we regard the outcome of analysis to be inclusive (for example), if the analysis of *any* of the pieces of evidence proved inclusion. Thus, the outcome of exclusion is applied only to cases that had no result other than exclusions. It is therefore not a reliable indicator of rate of suspect exoneration.

Several aspects of Table 6 are notable. First, as already suggested by Table 5, we note a very low rate of trace evidence analysis- performed in just a fraction of a percent of the cases in our sample- relative to drug, DNA, firearms, and fingerprint evidence analysis. None of the categories of forensic analysis is routine, with the arguable exception of fingerprints. Forensic evidence analysis is a less common feature of non-lethal, non-sexual offenses (again with the exception of fingerprints). These findings are consistent with our interviews with detectives about the utility of forensic evidence analysis: associative evidence (often produced by trace evidence analysis) is useful to an investigation less often than individualizing forensic evidence, and forensic evidence analysis on the whole is usually not part of aggravated assault, robbery, and burglary investigations.

Across offense categories, DNA tests resulted in more inclusions than exclusions. Where firearms evidence is analyzed, it also implicates a suspect more often than not. This observation is also in line with detective accounts of the utility of these analyses to their investigations. Recognize, however, that the exclusion rate shown may be far lower than the total exclusion rate, as only cases with no inclusions are counted in this table. Finally, crime laboratories appear to be diligently uploading CODIS and NIBIN, as the fraction of cases uploaded tracks closely with the fraction of cases with probative results.[63]

Estimating the strength of correlation between forensic evidence testing and case disposition

In Table 6 we saw the results of the forensic analyses performed and the very small fraction of cases in which the analyses were performed prior to arrest. But how much difference do these tests make to the resolution of the case? To answer this question, we estimate linear probability models of the following form:

$$y_{ijt} = \alpha + \boldsymbol{\beta X_{ijt}} + \boldsymbol{\gamma Z_{ijt}} + \eta_j + \eta_t + \varepsilon_{ijt} \qquad (1)$$

Where y_{ijt} is an indicator for whether a particular binary outcome (e.g. arrest, decision to file charges, conviction) was made in case *i* occurring in county *j* in year *t*; $\boldsymbol{X_{ijt}}$ is a vector of indicator variables representing each of the forensic testing categories; $\boldsymbol{Z_{ijt}}$ is a vector of victim characteristics including victim gender and ethnicity – it may also include arrestee characteristics for post-arrest outcomes; η_j and η_t are county and year fixed effects respectively, and is an error term. Our interest centers on the $\boldsymbol{\beta}$ vector of coefficients, which captures the effect of forensic testing on the outcome of interest.

As explained earlier, our interest is in modeling conditional probabilities, i.e. the regression equation above is estimated at each stage of the process while restricting the sample to cases that have progressed to that stage. Selection bias is a natural concern in this context-- as a case progresses from arrest to sentencing, the sample shrinks in a non-random way. Thus, for example, the sample of cases that reach the stage where charges are filed is a selected sub-sample of the set of cases that were referred to the DA, which in turn are a selected sample of the cases in which an arrest was made. This non-random selection tends to bias our estimate of the effect of forensic analysis on the probability that a case progresses from one stage to the next. Some researchers attempt to correct for sample selection bias using Heckman's sample selection correction. Unfortunately, this procedure works poorly unless one can identify credible exclusion restrictions, i.e. variables that enter the selection equation but not the final equation of interest in order to isolate the selection effect.[64] Because we found no plausible exclusion restrictions, we chose not to use the Heckman

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[63] Bear in mind some DNA inclusions are bound to be victim profiles, which are not to be entered into CODIS.

[64] *See generally* Shawn Bushway, Brian D. Johnson & Lee Ann Slocum, *Is the Magic Still There? The Use of the Heckman Two-Step Correction for Selection Bias in Criminology*, 23 J. QUANT. CRIMINOL. 151 (2007) (critically reviewing literature and criticizing widespread inappropriate use of Heckman method).

correction. The reader is therefore warned to exercise caution in interpreting the estimated effects.

A second threat to causal identification arises from omitted variables. For example, certain unobserved aspects of a crime may influence law enforcement agencies' commitment to solving the case;[65] if so, these unobserved factors would likely influence the outcomes of interest as well as the decision to collect and analyze forensic evidence. This would tend to bias estimates of a causal effect of forensic evidence collection and analysis on case outcomes. To mitigate this problem, we include a number of controls in our regressions, including victim and arrest characteristics, as well as jurisdiction fixed effects.

Similarly, there may be interdependence between the decision to test evidence and the decision to arrest/charge/etc. The chronology of events is key: As we saw in Table 5, for many crimes in our sample, forensic testing occurs *after* a particular outcome of interest has occurred (e.g. arrest), and therefore cannot logically have contributed to this outcome. There may however be a strong association between the particular outcome and forensic testing, reflecting reverse causation. For example, once charges have been brought, law enforcement agencies may become more likely to submit evidence for testing. This problem is most pronounced when we are looking at outcomes in the early stages of a case, but becomes less severe in later stages (e.g. conviction and sentencing) because these later outcomes almost always occur after any forensic testing. In the next section, we explain how we attempt to mitigate reverse causality when looking at early outcomes.

What is the correlation between forensic evidence testing, arrest, and charging decisions?

Our qualitative interviews, along with the statistics on pre-arrest forensic testing, together suggest that forensic testing may not play an important role in

[65] Only a little imagination is required to see how unobserved crime characteristics can affect forensic evidence collection, subsequent analysis, and even the results of analysis. First, in some scenarios there may not be any forensic evidence to collect. For example, if a man is robbed at gunpoint on a street corner, the encounter is unlikely to produce any forensic evidence. Forensic evidence may also be dispersed or destroyed by a conscientious perpetrator, the elements (rain, wind, animals), or a distraught victim. Forensic evidence may go uncollected because it is overlooked or deemed unnecessary (e.g. casts of suspect footwear impressions for a crime witnessed by dozens of people). Conversely, evidence may be collected and analyzed to guard against accusations of negligence, particularly in high-profile cases, even when it is highly unlikely to contribute useful information (e.g. sampling and testing a pool of blood under the victim of a stabbing to confirm the blood originated from them). Our supposition is that a majority of forensic evidence collection and analysis occurs because detectives and prosecutors are confident about its probative value. The anticipated value of the evidence is a function of their experience and details they gather in the course of their investigations, including an assessment of the importance and likelihood of bringing the perpetrator(s) to justice, most of which we do not observe.

the decision to make an arrest, especially when other evidence is available. However, there may also be instances in which forensic testing may be required to identify putative suspects in the first place. In this context, some types of forensic evidence may be more valuable than others.

We allow the data to speak on this matter, by examining the effect of forensic testing on arrest and charging decisions. A key concern is that the majority of forensic testing occurs after arrest (and after charges have been filed). It is therefore critical to account for the chronology of testing vis-à-vis arrest if we are to avoid picking up the effects of arrest on subsequent decisions to test forensic evidence, rather than the other way around. Our unusually comprehensive data collection effort is geared toward addressing this challenge: For each category of forensic analysis, we consider testing to have been done if the result was known prior to arrest, i.e. we define an indicator for forensic testing (for each category of analysis) that takes the value 1 for a particular case if the results were known prior to arrest. It is important to note that this definition also includes cases in which there was no arrest.

We can now estimate the regression equation, separately for arrest and charging decisions as the outcome variables of interest. In the case of charging, we condition the sample on cases in which an arrest was made. Table 7 presents the results of these regressions.

Table 7: Association of forensic testing with arrest and charging decisions

	(1) Arrested	(2) Charges filed
Trace evidence analyzed	-0.018	
	(0.498)	
Drug analysis	-0.043	0.060
	(0.100)	(0.189)
DNA analysis	-0.044	0.046
	(0.049)	(0.096)
Firearms/toolmarks analysis	-0.052	0.158**
	(0.044)	(0.070)
CODIS hit obtained	0.199**	-0.061
	(0.099)	(0.174)
NIBIN hit obtained	-0.015	-0.076
	(0.152)	(0.172)
Observations	2,721	647
Means of dependent variables	0.362	0.640

Notes: Robust standard errors in parentheses. The regressions control for jurisdiction fixed effects, offense fixed effects and binary indicators for whether any of the victims was female, and whether any of the victims was white. The regression in Column 2 also controls for arrestee gender and race.

Statistical power is clearly an issue here, with many of the coefficients lacking precision. In the case of arrest (Column 1), With the exception of the coefficient on CODIS result (which is significant at 5% level), which does suggest a strong positive correlation with the probability of arrest (the point estimate implies obtaining a CODIS hit results in a 19 percentage point increase in the probability of arrest), none of the coefficients on the forensic testing indicators is statistically significant, and many of them have the wrong sign. The results in Column 2 are, although even here precision is clearly lacking. With regard to the charging decision, firearms/toolmarks analysis is associated with a 15.8 percentage point increase in the probability of charges being filed (conditional on arrest having been made), although precision is clearly lacking. Note that in Column 2, we are not able to estimate a coefficient on trace analysis due to insufficient variation in the sample.

These results are consonant with the observation (see Tables 5 and 6) that DNA and firearms analysis are the two categories of forensic analyses that are most commonly requested by law enforcement. The results also largely comport with what we heard from prosecutors, most of whom said that charges are usually filed before forensic evidence has been analyzed (estimates ranged from 75 to 90 percent of the time), adding that most cases their office handles are strong enough to warrant filing of charges without forensic testing results in hand. Two Sedgwick County prosecutors said the agency made every effort to get forensic testing done ahead of filing to reduce the risk of charging innocent people. Prosecutors pointed out that often when analysis precedes filing, it precedes arrest also, as with forensic database "cold hits."

We did observe an increase in the probability of charges being filed in rape cases when trace evidence is tested. Aggravated assault arrestees are apparently more likely to be charged in cases in which firearms evidence and fingerprints are tested; this may be a proxy for the weapon having been recovered, which would be important for establishing the aggravated circumstances of the assault. Similarly, a charge of robbery is more supportable with DNA evidence to show that force and/or weaponry were involved.

How does forensic evidence affect the plea-bargaining process?

Once charges have been filed, multiple outcomes become possible. This stage entails not just the decision to plead or go to trial, but also the options of dismissal and diversion, and sometimes between trial by judge or jury. This phase also involves decisions that are made jointly by prosecutors and the defense (i.e. whether to offer and/or accept a plea versus accepting the greater risk of a bench or jury trial).[66]

[66] For the prosecution, a plea agreement is an expedient way to obtain convictions, the outcome by which their performance, and that of their elected bosses, is often evaluated. Defense attorneys will consider whether the odds and stakes of conviction at trial for the charged offense(s) are such that pleading guilty to a lesser offense is the more prudent option to

Theoretically, forensic evidence could make plea bargains either more likely or less likely. Strong forensic evidence against a defendant could make the defense less eager to go to trial, but might also make the prosecution less likely to offer a plea agreement with terms a defendant is willing to accept. So the relationship between forensic evidence and plea agreement rates is an interesting empirical question.

According to the Bureau of Justice Statistics, defendants in the nation's 75 largest counties charged with the five Part I offenses examined in our study were adjudicated through plea agreements at the rate of 51 percent for murder, 60 percent for rape, 52 percent for aggravated assault, 64 percent for robbery, and 67 percent for burglary.[67] Plea agreement rates for the study sites are shown in Table 8 below. In our sample, homicide plea agreement rates are several points lower, and aggravated assault, robbery, and burglary plea agreement are markedly higher. The difference may be due to our sample covering a three or four-year period, rather than a single year, 2009, examined by Bureau of Justice Statistics or simply a function of the particular jurisdictions in our study.[68]

Table 8: Adjudication of Charged Defendants in Sample

	Dismissed	Diverted	Plea	Jury Trial	Bench Trial
Homicide	3.0	0.5	45.5	47.7	1.4
Rape	4.3	0.9	59.1	25.2	0.9
Aggravated Assault	10.9	0.0	72.8	6.8	0.0
Robbery	15.1	2.6	71.1	10.8	0.4
Burglary	5.5	0.0	78.1	5.5	0.0

We examine the relationship between forensic evidence and the outcome obtained in this stage by looking at how the former correlates with each of the possible outcomes, using the linear probability regression specification as before. Because diversions and bench trials account for a small fraction of outcomes in our sample, we group the outcomes into the following three categories: (1) dismissal or diversion, (2) plea bargain, (3) bench or jury trial. The regression samples only include cases in which charges were filed.

Because we do not know precisely when this stage of the process was resolved, we cannot be sure which pieces of forensic evidence were available to inform the decision. As we saw in Table 5, this is an important issue, given that

recommend to their client. Judges may also encourage plea agreements to reduce the backlog of pending trials on their calendars.

[67]Reaves, Brian (2013). *Felony Defendants in Large Urban Counties, 2009- Statistical Tables*, Bureau of Justice Statistics, Washington, D.C., p. 24. About one third of felony defendants either have the charges dismissed (25 percent) or are adjudicated through pretrial diversion/deferred prosecution (9 percent). Of the remaining two-thirds of felony defendants, about 96 percent are adjudicated through plea agreements.

[68] One of the study jurisdictions, Sedgwick County, is not among the 75 largest counties in the United States..

rates of forensic testing prior to plea are still relatively low compared to the same rates at the time of trial. We opt to err on the side of caution, by restricting attention as before to testing that was conducted prior to arrest.
Table 9 below presents the results of the estimation.

Table 9: Association of forensic testing with post-charging outcomes

	(1) Dismissal/Diversion	(2) Plea	(3) Trial
Trace evidence analyzed			
Drug analysis	0.011	-0.160	-0.033
	(0.017)	(0.265)	(0.252)
DNA analysis	-0.007	-0.140	0.255**
	(0.012)	(0.129)	(0.113)
Firearms/toolmarks analysis	-0.027**	-0.085	0.119
	(0.013)	(0.085)	(0.084)
CODIS hit obtained	-0.002	0.171	-0.330
	(0.027)	(0.230)	(0.233)
NIBIN hit obtained	0.282	0.150	-0.431
	(0.279)	(0.290)	(0.299)
Observations	414	414	414
R-squared	0.119	0.200	0.233

Notes: Robust standard errors in parentheses. The regressions control for jurisdiction fixed effects, offense fixed effect, race and gender of the victim as well as the arrestee.

As in the pre-arrest stage, both DNA analysis and firearms analysis appear to be important predictors of the outcome in the post-charging stage. The pattern of coefficients across the three outcomes indicates that when DNA and/or firearms analysis occur, the case is more likely to proceed to trial than to be pled out or dismissed. Interestingly, NIBIN and CODIS hits are associated with an decreased probability of trial relative to plea bargain, although these coefficients are not as well estimated.

Whether each of these types of forensic testing confers an advantage on the prosecution or the defense is difficult to infer from these results, given that we are merely identifying the average change in probability for all forensic testing (rather than the effects of the various outcomes of the test, i.e. exonerating, implicating or inconclusive).[69] More generally, however, it is important to

[69] We are unable to shed further light on this question because even though we have information on the outcomes of the various forensic analyses, the data are not detailed enough for us to discern which of the various samples of evidence in a particular evidence category is associated with which particular testing result, implying that we do not know at which point in time each of

understand that the results in Table 9 present only a very summary description of an extremely complex negotiation phase (more on this shortly).

Before proceeding further, we note some statistical implications of our decision to restrict attention to testing that occurred before arrest. First, doing so has the disadvantage of sacrificing power (given that rates of testing prior to arrest are low). To the extent that we are ignoring some forensic analysis that occurred after arrest but before the dismissal/plea/trial decision was made, we will also effectively run the risk of understating the strength of the correlation.[70] Nonetheless, our prior is that the biases due to reverse causation are significant enough to warrant this restrictive definition of the testing variables.

To assess the effect of our restriction, we also present results from a set of estimations in which testing is considered to have occurred if it occurred at all at any point in the justice process. The results are in Table 10 below.

Table 10: Association of forensic testing with post-charging outcomes (including all testing)

	(1)	(2)	(3)
	Dismissal/Diversion	Plea	Trial
Trace evidence analysed	-0.062**	0.124	-0.015
	(0.030)	(0.145)	(0.146)
Drug analysis	0.023	-0.160**	0.132**
	(0.022)	(0.066)	(0.059)
DNA analysis	-0.012	-0.238***	0.286***
	(0.013)	(0.073)	(0.076)
Firearms/toolmarks analysis	0.014	-0.021	-0.003
	(0.035)	(0.068)	(0.066)
CODIS hit obtained	0.001	0.268***	-0.257***
	(0.031)	(0.092)	(0.094)
NIBIN hit obtained	0.020	-0.065	0.048
	(0.042)	(0.080)	(0.076)
Observations	737	737	737
R-squared	0.115	0.127	0.215

Notes: Robust standard errors in parentheses. The regressions control for jurisdiction fixed effects and binary indicators for whether any of the victims was female, and whether any of the

the probative results was obtained relative to the outcomes we are studying. However, this timing issue can largely be ignored when we look at conviction and sentencing outcomes.

[70] To see this point, suppose, to start with, that DNA analysis (for example) increases the probability of trial. To estimate this effect, we will be comparing cases that had DNA analysis prior to arrest to those that did not. But what if the latter set of cases in fact had (unknown to us) DNA analysis done immediately after the arrest? In that event, we would observe very little difference in trial rates across the two groups, and would incorrectly conclude that DNA analysis has no effect at this stage of the process.

victims was white, as well as binary indicators for whether any of the arrestees was female and whether any of the arrestees was white.

We notice that while the effect of DNA analysis continues to be qualitatively similar in sign, magnitude and statistical significance, firearms/toolmarks analysis, drug analysis and NIBIN hits actually reverse their signs, suggesting conclusions opposite to those in Table 9. These results highlight the importance of accounting carefully for event chronology.

Responses from our qualitative interviews underscore the complexity of the relationship between forensic evidence and the disposition of cases once charges have been filed. Several prosecutors indicated that forensic evidence was routinely sent for testing before plea negotiations. A deputy district attorney in Allegheny County who handled homicide cases stated that forensic evidence is almost always tested ahead of plea bargaining because he and his colleagues want to know exactly what they have on the table when negotiations begin. But in other jurisdictions, homicide prosecutors said they didn't engage in plea bargaining for homicides, so it didn't really matter whether they had forensic test results at that stage. Most assistant district attorneys reported less consistency in having forensic evidence analyzed prior to plea bargaining negotiations. Some prosecutors reported that they generally tried to have forensic evidence tested, but that it was sometimes not possible because of the crime laboratory's backlog, especially for less serious cases (i.e. robberies and burglaries in which victims were unharmed). Others reported that sometimes they didn't need forensic evidence test results to have "a good feel" for the case. Several prosecutors in sexual assault units reported that testing requests depended on the case, for example whether the defendant was claiming consent or not.[71]

Prosecutors said they would sometimes delay negotiations until they had received forensic results. Some reported they would delay plea-bargaining if the forensic evidence results could potentially strengthen their case. They explained that the sort of plea bargain offered depends in part on their confidence in winning at trial, which in turn is affected by the probative value of the forensic evidence to the state's case.

By the same logic, a few of the prosecutors we interviewed indicated they might be inclined to wait for DNA evidence results in particular before beginning negotiations if there were obvious weaknesses in their case, like witness credibility issues. One respondent stated that DNA evidence was more important than other traditionally strong pieces of evidence, such as a defendant's confession. Another stated that if he has one witness and forensic evidence, he is more likely to go to trial (so the stronger the case, the less likely they are to plead out).

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[71] If the defendant admitted to sexual relations with the victim, then the probative value of DNA evidence is limited to confirming this fact.

There were differences of opinion, however, over how the presence of forensic evidence affected case disposition, as other prosecutors indicated that the presence of inculpatory forensic evidence increased rather than decreased the likelihood of a plea. Said one, "If we have DNA evidence, then we have the upper hand, and don't have to give away the farm to get the case resolved during negotiations." Several respondents indicated that DNA evidence made them more comfortable about resolving the case, and one acknowledged that when DNA results implicated the perpetrator in a mixture with an unknown third party, it increased his willingness to offer a plea.

Others described the effect of forensic evidence on plea bargain likelihood as highly circumstance-dependent. For example, the probative value of forensic evidence was often limited in self-defense cases, mental defense cases, or a sexual assault case in which consent is the issue. In contrast, forensic evidence is an important factor when the identity of the perpetrator is at issue. More than one prosecutor opined that forensic evidence was no more or less important than other factors, such as eyewitness accounts and other circumstantial evidence.

Our experimental survey allowed us to empirically test the prosecutors' statements on the effect of forensic evidence on plea-bargaining. As explained in Section II Part D, we created a hypothetical criminal case and varied the type of forensic evidence available in the hypothetical. Criminal defense attorneys and prosecutors either viewed a hypothetical robbery case featuring DNA evidence against the defendant, or a case containing associative forensic evidence (glass fragments) against the defendant. Attorneys who viewed the case with DNA evidence received further information -- either that testing indicated there was a very low probability that another person contributed the sample, or that testing revealed a more ambiguous finding. All other features of the robbery case were identical between conditions. We then asked attorneys to indicate the likelihood, from 0 to 10, that they would offer/accept each of the potential plea bargains – five years, three years, and one year in prison in exchange for a guilty plea.

Table 11: Prosecuting Attorneys' Mean Likelihood Ratings of Offering Plea Agreements

	Highly Individualizing evidence	Individualizing evidence, partial match	Associative evidence
Five-year plea	5.53 (SD = 4.17)	6.33 (SD = 2.91)	7.10 (SD = 3.28)
Three-year plea	3.38 (SD = 2.45)	4.24 (2.82)	5.35 (SD = 3.47)
One-year plea	2.29 (SD = 2.95)	2.94 (SD = 2.75)	1.85 (SD = 1.27)

Table 12: Defense Attorneys' Mean Likelihood Ratings of Accepting Plea Agreements

	Highly individualizing evidence	Individualizing evidence, partial match	Associative evidence
Five-year plea	3.72 (SD = 2.91)	2.67 (SD = 1.94)	2.28 (SD = 1.53)
Three-year plea	6.56 (SD = 2.71)	4.22 (SD = 2.16)	4.24 (SD = 2.22)
One-year plea	9.22 (SD = 2.76)	6.44 (SD = 2.59)	7.53 (SD = 2.85)

Unsurprisingly, the tables are mirror images of one another. Prosecutors indicated they were least likely to offer one-year pleas and defense counsel indicated they were most likely to advise accepting one-year pleas, while the converse was true for five-year pleas. Similarly, the more inculpatory the forensic evidence, the less likely the prosecutors were to offer a plea and the more likely the defense attorneys were to recommend accepting one if offered.

Despite the clear pattern in the mean responses, most of the differences are not actually statistically significant. For prosecuting attorneys, we did not observe statistically significant differences in reported likelihood of offering a five-year, three-year, or one-year sentence deal by type of evidence. We did, however, observe that the quality of forensic evidence had a marginally significant effect on the likelihood prosecutors indicated they would offer a three-year sentence in exchange for a guilty plea.[72] Prosecuting attorneys who viewed a case containing individualizing evidence with a complete match were least likely to offer a three-year deal, followed by attorneys who viewed a case containing DNA evidence with a partial match and associative evidence.

We did not observe statistically significant differences in defense attorneys' reported likelihood of accepting a five-year sentence plea bargain under the various forensic evidence scenarios, but the hypothetical evidentiary conditions did significantly defense attorneys' likelihood of accepting a three-year sentence in exchange for a guilty plea.[73] Because we observed a significant effect of evidence type on the defense attorneys' likelihood of accepting a three-year sentence, we conducted a post-hoc Tukey test, or a Tukey HSD (honest significant difference test), used after an ANOVA to determine which of the conditions are significantly different from each other. The post-hoc Tukey test showed that defense attorneys who viewed a case containing individualizing evidence with a complete match were significantly more likely

[72] $F(2,50) = 1.983$, $p = .1$.
[73] $F(2,50) = 5.69$, $p<.01$.

to recommend that their client accept a three-year deal[74] compared to attorneys who viewed a case containing DNA evidence with a partial match[75] or associative evidence.[76] We also observed a statistically significant difference between conditions in defense attorneys' likelihood of accepting a one-year sentence in exchange for a guilty plea.[77] A post-hoc Tukey test showed that defense attorneys who saw the individualizing evidence scenario with a complete match were significantly more likely to recommend that their client accept a one-year deal[78] than attorneys who viewed a case containing DNA evidence with a partial match[79] or associative evidence.[80]

By controlling all extraneous factors and only manipulating forensic evidence variables, the experimental survey methodology allows us to draw strong causal conclusions about the role that different types of forensic evidence play in attorneys' perceptions of evidence strength, case strength, and the likelihood of plea bargains.

The results suggest that the strength of forensic evidence plays a role in the plea-bargaining process. For prosecuting attorneys and somewhat for defense attorneys, the strength of forensic evidence did not significantly influence attorneys' reported likelihood of offering/accepting plea bargains at the extremes. Most prosecutors were likely to offer and most defense attorneys were likely to reject a five-year plea bargain, regardless of the strength of forensic evidence in the case.

However, forensic evidence did play a role when attorneys were considering more moderate plea bargains of a three-year sentence. Defense attorneys were significantly more likely to accept a three-year plea offer when their hypothetical client was implicated by highly individualizing DNA evidence than they were when the client was implicated by associative evidence. We observed similar patterns in prosecutors' willingness to offer a three-year plea bargain – highly individualizing DNA evidence conditions were less likely to result in a plea bargain offer than less inculpatory partial DNA evidence or glass fragment evidence.

Relatedly, prosecutors and defense attorneys were also asked about the strength of the evidence and the probability they would win if the case were brought to trial. We examined attorneys' ratings of agreement on a scale of one to ten, with higher ratings indicating greater agreement with the statement, "the evidence against the defendant in this case was weak."

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[74] $M = 6.56$ ($SD = 2.71$).
[75] $M = 4.22$ ($SD = 2.16$).
[76] $M = 4.24$ ($SD = 2.22$) .
[77] $F(2,50) = 4.72$, $p = .01$.
[78] $M = 9.22$ ($SD = 2.76$).
[79] $M = 6.44$ ($SD = 2.59$).
[80] $M = 7.53$ ($SD = 2.85$).

Table 13: Attorneys' Mean Ratings of Agreement with Statement, "The Evidence Against The Defendant in This Case Was Weak"

	Individualizing evidence, complete match	Individualizing evidence, partial match	Associative evidence
Prosecutors	2.76 (SD = 1.82)	3.89 (SD = 1.97)	4.95 (SD = 1.82)
Defense Attorneys	3.06 (SD = 1.21)	5.65 (SD = .86)	5.22 (SD = 1.56)

Results were significant for prosecutors and defense attorneys alike.[81] Defense attorneys who viewed the case with single-source, individualizing DNA evidence were significantly less likely to agree with the statement[82] than defense attorneys who were presented with hypothetical cases featuring partial match DNA evidence[83] or associative evidence.[84] We also observed significant differences in defense attorneys' ratings of the probability they would win an acquittal if the case were to go to trial.[85] Defense attorneys who were presented with the complete match DNA evidence scenario were less confident[86] that they would win an acquittal than attorneys presented with the other two scenarios.[87]

For prosecuting attorneys, we also observed significant differences in attorney's level of agreement with the statement, "the evidence against the defendant in this case was weak."[88] Prosecuting attorneys who viewed the complete DNA match case were significantly less likely to agree with the statement[89] than prosecutors who viewed a case a case containing associative evidence[90] and ratings for the partial match condition were significantly different from the other two groups.[91] We did not observe significant differences between conditions for prosecuting attorneys ratings of the probability they would win a conviction.

Table 14: Attorneys' Mean Ratings of Probability They Would Win at Trial

	Individualizing evidence, complete match	Individualizing evidence, partial match	Associative evidence

[81] The result of the one way ANOVAs: $F(2,50) = 21.98)$, $p < .001$
[82] M = 3.06 (SD = 1.21).
[83] M = 5.65 (SD = .86).
[84] M = 5.22 (SD = 1.56). This was the result of a post-hoc Tukey.
[85] $F(2,50) = 9.14$, $p < .001$
[86] M = 42.2% (SD = 1.86)
[87] M = 66.5% (SD = 2.06). This was the result of a post-hoc Tukey test.
[88] $F(2,52) = 6.3$, $p < .01$.
[89] M = 2.76 (SD = 1.82).
[90] M = 4.95 (SD = 1.82). This was the result of a post-hoc Tukey HSD test.
[91] M =3.89 (SD = 1.97).

Prosecutors	80.0% (SD = 3.00)	69.4% (SD = 2.26)	65.5% (SD = 2.16)
Defense Attorneys	42.2% (SD = 1.86)	63.3% (SD = 1.57)	66.5% (SD = 2.06)

Forensic evidence does affect attorneys' perceptions of case strength and their likelihood of winning at trial. When the defendant was tied to the crime via a partial DNA match or glass fragments consistent with the shattered glass at the scene, the defense attorneys rated the case as less strong and had more confidence they would win at trial than when the case contained an exact, full-profile DNA evidence. There was no significant difference in attorneys' evaluation of partial DNA evidence and glass fragment evidence – both were rated as less strong than complete DNA evidence.[92]

To summarize, forensic analysis is correlated with whether a case will go to trial, but in a fairly complex way. In assessing the forensic evidence, each side attempts to predict how the evidence will affect the outcome of a trial.[93]

E. *What is the correlation between forensic evidence and conviction?*

The assessments made by each side are usually based on prior experience, and may accurately reflect the actual effects of forensic analysis on trial outcomes. We can use our data to objectively estimate the importance of forensic testing on trial outcomes. At this stage of the justice process, we can now bring to bear the detailed information on the outcomes of testing, and differentiate between the effects of inconclusive, exculpatory and inclusive forensic results.

Our quantitative analysis focuses on two outcomes: (i) Conviction on any charge, (ii) Conviction on the most serious charge. For each forensic testing category (with the exception of drug testing, for which we do not observe test results), we construct a set of dummy indicators that correspond to the various possible outcomes of the test (as in Table 5 above). We then estimate linear probability models as before, using the forensic testing outcome indicators as explanatory variables, while conditioning the sample on cases that either pled out or went to trial.

Table 15 below presents the results. For each forensic evidence category, the omitted group corresponds to an inconclusive result (i.e. neither indicating exclusion nor inclusion): Thus, all other coefficients are estimated relative to this base group. This choice of omitted category allows us to simultaneously answer two questions of interest: First, what is the estimate for no forensic testing, relative to a situation in which forensic testing is conducted but does not

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[92] *See* Bushway et al, *supra* note 50 at 740 (study using similar methodology to measure effect of different kinds of evidence on plea bargaining outcomes).

[93] *See id.* (finding support for "shadow of trial" hypothesis that plea bargaining will reflect predictions about likely trial outcomes).

turn up any conclusive result, i.e. is there a "placebo effect" of testing? Second, to what extent does a probative result matter? Implicitly, the reference category in this question is a situation in which testing is conducted but does not turn up a probative result.

Table 15: Association of forensic test outcomes with conviction

	(1)	(2)
	Conviction on any charge	Conviction on most serious charge
Trace evidence (Omitted category=Evidence analyzed but inconclusive)		
Not analyzed	-0.054	-0.124
	(0.074)	(0.089)
Exclusion	-0.032	-0.019
	(0.085)	(0.108)
Inclusion	0.007	0.051
	(0.073)	(0.087)
Drug analysis	-0.213	0.056
	(0.131)	(0.117)
DNA evidence (Omitted category=Evidence analyzed but inconclusive)		
Not analyzed	0.005	-0.073
	(0.118)	(0.147)
Exclusion	0.071	0.183
	(0.138)	(0.161)
Weak inclusion	0.226**	0.277*
	(0.115)	(0.146)
Strong inclusion	0.140	0.095
	(0.111)	(0.142)
Firearms evidence (Omitted category=Evidence analyzed but inconclusive)		
Not analyzed	0.034	-0.026
	(0.059)	(0.071)
Exclusion	-0.266	-0.319
	(0.186)	(0.215)
Inclusion	0.043	-0.006
	(0.071)	(0.088)
CODIS match (Omitted category=No match obtained)		
Search not performed	0.070	0.049
	(0.067)	(0.094)
Match	0.166***	0.142
	(0.064)	(0.101)

NIBIN match (Omitted category=No match obtained)		
Search not performed	-0.034	0.043
	(0.054)	(0.072)
Match	0.006	-0.176
	(0.167)	(0.222)
Observations	698	698
R-squared	0.072	0.139

Notes: Robust standard errors in parentheses. The regressions control for jurisdiction fixed effects, offense fixed effects, victim and arrestee gender and race. The regression samples are restricted to cases in which charges were filed but which were not dismissed or diverted.

With the necessary caveat about sample size, the results tell a story that is largely consistent with the findings from our qualitative interviews and the experimental survey. Inculpatory forensic evidence, particularly DNA and CODIS results, is associated with increased conviction probability. There is only a weak suggestion, however, that exculpatory forensic evidence matters: The coefficient on exclusionary trace evidence and exclusionary firearms evidence possess the right signs, but are poorly estimated. In general, as one would expect, the mere fact of analysis does not appear to predict conviction, as indicated by the fact that none of the coefficients on the "Not analyzed" indicators is statistically significant (although given our sample size and the standard errors we cannot confidently rule out non-zero effects).

It is also worth noting the possibility of a form of reverse causality -- that forensic evidence testing is the *result* of the perceived importance/strength of the case instead of the cause. This might be the result of the widespread perception on the part of prosecutors that jurors now had heightened and unrealistic expectations for forensic evidence, a phenomenon sometimes referred to as the "CSI Effect."[94] Prosecutors indicated that juror expectations are indeed an important factor in the decision to test forensic evidence[95] and have crime

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[94] See, e.g. Kathianne Boniello, "'CSI' has Ruined the American Justice System," New York Post, September 27, 2015 (interviewing several prosecutors and defense attorneys about jurors' newly-heightened expectations for forensic evidence).

[95] Anonymous interview with assistant district attorney:

> *Yes, we test [forensic evidence] to allay jury concerns. You need to prove your case beyond a reasonable doubt, and the defense can make it an issue if [evidence] wasn't tested. You kind of have to draw that balance: I may have 29 pieces to test, but it's not practical, it's not economical [to test them all]. We have to balance what to do. In one case I had to test cat and dog hairs and human hairs. I had already maxed out our lab with testing. I had already spent a lot. I had to try to balance: the evidence was probative, not as probative as what we get for humans, so we did [trace analysis] microscopic hair comparison. We were able to say these hairs are consistent with the suspect's pet's.*

laboratory personnel testify at trial.[96] While a few prosecutors acknowledged that jurors had actually become savvier about forensic evidence, making it easier to present, more often juror expectations for forensic evidence were described as unrealistically high.[97] The practice of testing forensic evidence to appease jurors rather than generate probative evidence may contribute to our findings.

Are concerns about forensic testing turnaround time warranted?

This is an especially intriguing question because the refrain heard so often in our interviews--the wish nearly every detective and prosecutor shared about their crime laboratory--was for increased capacity to complete requests more quickly.

Table 16: Average Analysis Times (in days)

	Allegheny	King	Sacramento	Bexar	Sedgwick	Overall
Hair	237	.	55.5	92.27	.	88.82
Fibers	.	.	30	85.88	.	74.7
FTIR	.	55.5	8.56	159.2	.	61.5
SEM_EDX	299.11	.	52.44	41.06	.	75.7
Fit match	39	.	.	59	.	52.33
Serology Screen	124.16	108.71	.	22.46	.	64.03
Blood pattern interpretation	.	209	.	.	.	209
YSTR	.	39	.	8	.	28.67
GC_MS	.	55.5	10.66	.	47.69	14.57
Drug ID	115.57	.	.	3	34.83	71.8
STR	88.09	105.11	290.24	55.12	66.56	135.2
Test fire	288	233.75	89.69	244.89	26.72	162.95
Comparison scope	200.52	247.86	104.5	272.88	44.17	171.37

Notes: Averages are calculated conditional on analysis being completed within the time-frame covered by the study

Looking at the average turnaround times for forensic testing our case sample in Table 16, one can understand why this concern was so often voiced. Few

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[96] Anonymous interview with assistant district attorney:

> *I think that their expectations have gotten much higher. Back when I started if we had an 8x10 color photo we were in great shape. Now they want DNA on everything. It does two things: we either send things to the lab, or we have someone from the lab testify to why it wasn't done. We do that much more often than we used to.*

[97] Several mentioned making a standard statement during *voir dire* to explain that the recovery of probative forensic evidence from a crime scene is not inevitable, and that many cases are proved beyond a reasonable doubt with only direct evidence.

categories of testing have a mean analysis time under a month, and for many the average is closer to three or four months, which means the wait for crime laboratory results may sometimes be much longer.[98] Moreover, the average turnaround times calculated here are conditional on analysis having been completed within the timeframe of the data that we collected, and therefore probably underestimate actual turnaround times by eliminating requests that had not been completed during the time of our study.

During our interviews, detectives and prosecutors were asked if forensic evidence testing delays ever enabled a suspect in a case of theirs, who would have been arrested had the test results been known, to commit additional crimes. Most said no, but several expressed a vague awareness that this had happened at some point in the jurisdiction, and two were able to recall specific cases. Apart from this scenario, interviewees said testing delays contributed to witness memory erosion, sometimes necessitated dropping and re-filing charges to comply with speedy trial requirements or sending items to private laboratories for rush analysis at a premium cost. Several prosecutors were quick to add, however, that their local crime lab tries to accommodate rush requests. A few also noted that lengthy adjudication times (years) are often due to crowded dockets, defense continuations or other factors unrelated to the crime lab's turnaround.

Does the institutional configuration of the crime laboratory have any effect on its productivity?

In light of these findings, it is natural to ask what determines turnaround times. In general, turnaround time is a function not only of crime lab constraints, but of other case circumstances that make the analysis more or less time sensitive. How a case is progressing through the investigation and judicial processes (e.g. whether or not there is a suspect in custody, how prepared the prosecution and defense is for trial) will have a bearing on turnaround time. From a policy perspective, however, we would like to understand if there are specific institutional/structural factors that affect the efficiency of forensic evidence processing? We attempt to answer this question by using the Census of Forensic Labs data to estimate the relation between crime laboratory output and the "inputs." We use the notion of a production function as a useful organizing framework. Consider the following functional relationship between lab clearance rate (i.e. cases cleared during the calendar year as a fraction of the total number of requests received by the lab) and inputs:

$$Y_{it} = \Phi_i {L_{it}}^{\alpha} {B_{it}}^{\beta}$$

[98] Table 26 has empty cells because some tests and technologies were not available at the local crime lab or not used in the sample of cases.

where Y_{it} is the clearance rate of lab *i* in year *t*, L_{it} is the average number of full-time laboratory employees per case, B_{it} is the average operating budget per case (as a proxy for "capital", i.e. equipment) and Φ_i represents an index of the laboratory's technical efficiency (analogous to the economic literature on production functions, Φ_i can be intepreted as Total Factor Productivity). Writing this equation in logs, we have:

$$y_{it} = \alpha l_{it} + \beta b_{it} + \phi_i$$

where lower-case letters now denote logarithms of the original variables.

We first estimate the effect of workforce and budgets on crime lab output. These effects are represented by the coefficients α and β, which can be seen to be the elasticity of "output" (i.e. case clearance rate) with respect to *L* and *B* respectively. We estimate these coefficients by means of an ordinary least squares (OLS) regression of y on l and b. That this may not yield unbiased estimates of α and β follows from the possibility that labs that are more productive may receive greater budget allocations and may also be able to increase their workforce. This would imply that the unobserved productivity term ϕ_i is correlated with l and b, thereby biasing the estimates of their partial effects. A straightforward solution to this problem is to use the panel dimension of the data: The fact that each laboratory is observed multiple times allows us to utilize a fixed-effects estimation strategy that controls for the unobserved productivity term. The key assumption underlying this method is that lab productivity is fixed over time.[99]

Our interest also lies in understanding the underlying determinants of lab efficiency, i.e. we would like to unpack ϕ_i. We think certain factors may play a key role, namely (i) the incentive structure, in terms of the laboratory's funding sources, (ii) organizational structure, in terms of controlling authority, and (iii) the use of an electronic lab management system (LIMS). Information on funding sources is only available for the 2005 and 2009 rounds of the census. We capture incentive structure in a single variable that represents the percentage of funding that the lab receives from fees, as opposed to funding from grants and local and state governments, the hypothesis being that labs that are oriented

[99] A more sophisticated approach would be required if in fact productivity were thought to be evolving over time. Because the data at hand are not rich enough to implement the more advanced methods that have been suggested in the literature on production function estimation, we restrict ourselves to the simpler fixed-effects estimation. For examples in this literature *see e.g.* S. Olley & A. Pakes, A. *The Dynamics of Productivity in the Telecommunications Equipment Industry*. 64 ECONOMETRICA 1263-1295 (1996); J. Levinsohn, J. & A. Petrin, *Estimating Production Functions Using Inputs to Control for Unobservables*, 46 THE REVIEW OF ECONOMIC STUDIES 317-342 (2003); and M. Arellano & S. Bond, *Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations*, 58 REVIEW OF ECONOMIC STUDIES 277-297 (1991).

towards fee-for-service are likely to face greater pressures to be efficient. While organizational structure is difficult to fully capture, we include indicators for whether the lab is a state lab, a county lab or a municipal lab.[100]

Because these factors are (almost completely) time-invariant, the fixed-effects estimation will tend to sweep them out and thus make it impossible to estimate their effects. Instead, we utilize the approach suggested by Hausman and Taylor.[101] We begin by writing out the productivity term as follows:

$$\phi_i = \lambda_0 + \lambda_1 Fee_i + \lambda_2 Org_i + \lambda_3 LIMS_i + \epsilon_i$$

where Fee_i is the fraction of funding from fees, Org_i is a variable representing the organizational structure of the lab, $LIMS_i$ is an indicator for whether the lab uses a LIMS and ϵ_i is a residual term. We can now substitute () into () to write:

$$y_{it} = \alpha l_{it} + \beta b_{it} + \lambda_0 + \lambda_1 Fee_i + \lambda_2 Org_i + \lambda_3 LIMS_i + \epsilon_i$$

Under the assumption that Fee_i, Org_i and $LIMS_i$ are uncorrelated with ϵ_i, the Hausman-Taylor works by estimating the equation above using two-stage least squares (2SLS) to instrument the endogenous variables l and b with their deviations from their respective means, $l_{it} - \overline{l_i}$ and $b_{it} - \overline{b_i}$. The critical assumption is that Fee_i, Org_i and $LIMS_i$ are exogenous to unobserved elements of lab productivity. While this assumption cannot be tested, we attempt to increase its plausibility by including state and year fixed effects in the regression.

Table 17 below presents the results from the various regressions. Column 1 presents the results from a simple OLS regression of y on l and b. Column 2 adds state and year fixed effects to the specification. Column 3 adds laboratory fixed effects. Finally, Column 4 presents the results from the 2SLS regression.

Table 17: Estimating the lab production function

	(1)	(2)	(3)	(4)
l (log of employees per case)	0.12**	0.16**	0.32*	0.51*
	(0.05)	(0.08)	(0.17)	(0.26)
b (log of budget per case)	0.00	0.02	0.03	-0.05
	(0.02)	(0.02)	(0.04)	(0.05)
Percent funding from fees				0.60***
				(0.22)
LIMS				0.42*
				(0.25)
State lab				-0.09
				(0.09)

[100] Federal labs are excluded from the analysis.

[101] J. Hausman & W.E. Taylor, *Panel Data and Individual Fixed Effects,* 49 ECONOMETRICA 1377-1398 (1981).

County lab				-0.06
				(0.19)
Observations	627	487	627	245

*** $p<0.01$, ** $p<0.05$, * $p<0.1$; Standard errors in parentheses have been clustered at the level of the laboratory

The estimated elasticity of output with respect to labor per case increases as we move from the simplest (i.e. least demanding) specification to the 2SLS specification, and is statistically significant throughout. In contrast, the estimated elasticity of output with respect to operating budget is small and insignificant in all specifications. The 2SLS results reveal that fee-for-service creates a strong incentive effect: A 1 percentage point increase in funding from fees is estimated to increase case clearance rates by about 6%. The effect of employing a LIMS is also significant, increasing clearance rates by 40%. However, neither of the lab jurisdiction variables is found to have a significant effect, although we must again emphasize that these variables may only be weak proxies for organizational structure.

Of course productivity is not the only important aspect of institutional configuration: credibility and reputation are crucial as well. In our qualitative interviews we discussed the advantages and disadvantages of the lab's institutional configuration with detectives, prosecutors, and forensic scientists. Our study sites were somewhat diverse in terms of affiliation: three are independent, one is under the authority of the district attorney, and one is part of a state law enforcement agency that rarely uses it, conferring its own kind of autonomy.

Detectives, and prosecutors in jurisdictions with independent labs were mostly inclined to think that set up was ideal, enhancing the labs' objectivity and the credibility of expert witnesses at trial. A few prosecutors opined that different agendas (scientific versus adversarial, efficiency versus thoroughness) sometimes created friction that would be attenuated by association with law enforcement or the DA's office.

Crime lab personnel also felt that independence enhanced their individual and collective credibility. In Sacramento, two of the forensic scientists we interviewed said that if they could change one thing about the laboratory it would be to make its institutional configuration independent. However, laboratory personnel at independent laboratories noted that the separation made it harder to develop and maintain good working relationships, and thus to ensure detectives are well-trained in recognition, documentation, and preservation of forensic evidence.

IV. CONCLUSION

First, we return to our original research questions:

(1) What is the perceived utility of forensic analysis? How often is forensic evidence collected, how often is it analyzed, and when is it analyzed?

We note substantial diversity in the practice of the collection of forensic evidence. There appears to be little uniformity, even among relatively large departments, about the collection of forensic evidence in reported crimes other than homicide. If there is any common thread among our varied jurisdictions, it is the low rate of collection of forensic evidence in burglary and robbery reported crimes.

Second, we note considerable differences in the rate at which collected evidence is analyzed. This ranges from a high of 83% in San Antonio to a low of 19% in Seattle. Once again, the common thread was the low rate of forensic evidence analysis for reported robberies (<5%) and burglaries (<2%).

Third, forensic evidence is seldom analyzed prior to arrest. While there was considerable variation among sites, ranging from a high of 11.3% rate of pre-arrest firearms analysis in San Antonio to .7% in Seattle, in all categories of evidence, it was less than 12% and usually much lower. With few exceptions, the police in our sites were not using forensic evidence to identify suspects.

This is unfortunate. Pre-arrest suspect identification seems a stage at which the objectivity of forensic evidence and its lack of correlation with other sources of information about a suspect would recommend its use.

(2) What are the outcomes of forensic evidence testing? How often does forensic evidence testing yield useful information?

As noted above, in most reported crimes, forensic evidence is not analyzed. In crimes in which it is analyzed, it often yields inconclusive results, though this depends on the specific type of evidence analyzed. Forensic DNA and firearms testing results in excluding a suspect about twice as often as it results in supporting the case.

(3) What is the correlation between forensic evidence testing, arrest, and charging decisions?

Some kinds of forensic evidence are associated with an increase in arrest rates, but it is difficult to interpret because very little forensic analysis occurs prior to arrest and charging. DNA analysis was associated with about a nineteen percent increase in the probability of arrest in homicide cases.

Once arrest was controlled for, forensic evidence did not generally impact the likelihood of charges being filed. This was generally consistent with what we heard in our interviews, where prosecutors noted that arrests were usually made only in cases in which there was strong enough evidence to file charges.

(4) How does forensic evidence affect the plea-bargaining process?

Cases in which trace evidence is tested and found inconclusive or exclusionary are associated with pleas. In contrast, if the forensic trace analysis results in an inclusion, the case is more likely to go to trial. If DNA testing results in a weak inclusion, the case is more likely to plead out. If DNA testing results in a strong inclusion, the case is more likely to go to trial, partly, as interview comments and the evidence scenario experiment suggest, because the prosecution is less willing to offer an attractive plea agreement to the defendant. CODIS matches, however, tend to significantly decrease the chance of dismissal and increase the probability of plea bargain.

Our qualitative interviews found wide variation as to whether forensic evidence testing was performed prior to plea-bargaining. While some prosecutors reported wanting the results so they understood how strong of case they had, other prosecutors reported that they did not usually have them.

The results of the experimental survey study showed that forensic evidence played a role in the plea bargaining process, particularly in the middle range of cases in which a three-year plea bargain was at issue. A case in which there is stronger forensic evidence against the defendant is less likely to prompt the prosecutor to offer a plea bargain, and the defense counsel is more likely to counsel the defendant to accept it.

(5) What is the correlation between forensic evidence and conviction?

In our quantitative analysis, we found that forensic evidence matters at the trial stage when it provides conclusive evidence. Both inclusive and exclusionary evidence affect the likelihood of conviction on the most serious charges, with DNA having the most important effect.

We also found in the qualitative interviews that most prosecutors sometimes ordered forensic testing to meet unrealistic juror expectations. The testing may also reflect other aspects about the strength of the case that we are unable to observe.

Our experimental survey found that attorneys evaluated the likelihood of conviction in cases with DNA evidence as being higher than in cases with less individualizing forensic evidence.

(6) Are concerns about forensic testing turnaround time warranted?

Lengthy turnaround times are significantly associated with a decreased probability of conviction and shorter sentences. It is difficult to determine whether this is because law enforcement prioritizes testing in strong or high profile cases, or whether the delay itself is leading to this effect.

While police, crime lab, and prosecutor interviewees agreed that delays in analysis are a function of investigative priority, the lower the capacity, the more likely even critical analyses will not be completed in a timely manner. Analytical delays are a nuisance to law enforcement, but don't seem to enable criminals. However, longer turnaround times may contribute to unjust treatment for individuals who are detained pretrial.[102]

(7) What is the correlation between the institutional configuration of crime laboratories and their productivity?

Fee-based laboratories appear to have a substantial positive effect on clearance rates, implying efficiency gains in terms of more careful use of the crime laboratory by police and prosecutors, which may in turn free analysts to work submitted cases more thoroughly.

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[102] See, e.g. Ryan Gabrielson, *Unreliable and Unchallenged*, Pro Publica, October 28, 2016. https://www.propublica.org/article/unreliable-and-unchallenged (noting Las Vegas police use inaccurate road-side drug testing with high false positive rate; delays in lab testing lead to wrongful guilty pleas).

Employing a Laboratory Information Management System (LIMS) is also associated with increased productivity, increasing forensic test clearance rates by 40%, though having a LIMS may be a proxy for other variables we are unable to observe.

While we found that crime laboratory organizational affiliation is uncorrelated with clearance rates, this has no straightforward interpretation because the organizational affiliation variable was weakly specified. As a result, it is difficult to draw strong conclusions about the effect of crime lab organizational affiliation.

In the course of this study we made a number of other observations. The problem of antiquated, siloed data storage is considerable. In our study jurisdictions, lab information management systems (LIMS) were not evolved enough for our data to be gleaned electronically. Manual compilation of the data was necessary for our study. Law enforcement records management systems and court processing information systems were both vastly superior.

What can be done to improve the production and use of forensic science? First, we observed large variation in nearly every aspect of forensic evidence use and testing across our sample jurisdictions, with testing rates varying substantially by jurisdiction. While it is possible that these variations are efficient accommodations to local conditions, this seems highly unlikely. Best practices should be identified and adopted nationally for the collection, testing, and use of forensic evidence. The huge variation we observed strongly suggests there is substantial room for improvement on this front.

Second, there is very little use of forensic evidence prior to arrest and charging. This is partly a function of the political economy of forensic testing. Partly as a result of limited resources, testing in cases that are going to trial is prioritized over other cases. This means that use of forensic evidence for investigation or identification of a suspect rarely occurs. Efforts to encourage the use of the forensic science in the investigatory process, pre-arrest, would likely help realize the potential of forensic science. This could be furthered by either dedicating forensic lab resources to investigation or by increasing forensic lab capacities. It may also require a cultural shift to reduce the priority placed on forensic testing for cases going to trial and to increase the use of forensic evidence in the investigative phase of the case.

We also observed that fee-based laboratories have higher clearance rates. This suggests that using a pricing system to guide the use of forensic testing may improve its efficiency and reduce lab backlogs.

Finally, we noted that employing a lab information management system was associated with higher productivity rates among labs. We were surprised at how little integration of the lab information systems with police, prosecution, or court information systems. Ideally, authorized parties could access lab reports and the raw data directly. This increased transparency and oversight would increase confidence in our system of forensic science and perhaps reduce the incidence of lab scandals.

Over the last several years, the all too human imperfections of the criminal justice system have received increasing attention. In addition to wrongful convictions,[103] and racial bias in policing, commentators have noted that many jurisdictions have declining case clearance rates.[104] William Blackstone famously suggested that it may be better to let ten guilty persons go free than to convict a single innocent person,[105] but neither outcome is ideal, and our current justice system produces far too much of both.

We remain convinced that forensic science has considerable potential to improve the accuracy and reliability of the criminal justice system. By being relatively independent of the conventional police investigative process, it can, in theory, provide a decoupled check and reduce errors of both inclusion and exclusion – that is both the wrongfully convicted and the wrongfully acquitted.[106] But our results also show the vast gap between the theoretical potential of scientific evidence and its use in practice.

In theory, it can be used to identify suspects in a wide range of offenses. In practice, however, the use of forensic evidence is rare outside homicide, and its use almost always following arrest. In theory, it can be a truly independent verification of a suspect's guilt or innocence. In practice, however, we found that the lab typically worked closely with law enforcement, and usually knew in advance of testing what detectives and prosecutors were hoping to prove.[107] In theory, charging decisions are affected by the availability of forensic evidence. In practice, we found that prosecutors often did not have the results of forensic analyses at the time of charging. In theory, jurors correctly understand the

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[103] Samuel Gross, Jacoby Kristen, Daniel Matheson, Montgomery Nicholas, and Sujata Patil. *Exonerations in the United States, 1989 through 2003*, 95 Journal of Law and Criminology (2005) (estimating that 4% of serious felony convictions are wrongful); Brandon Garrett, Judging Innocence, 108 Colum L. Rev. (2008); John Roman, Kelly Walsh, Pamela Lachman, and Jennifer Yahner. et al. Post-Conviction DNA Testing and Wrongful Conviction 7-8 (2012) (estimating 5-8% wrongful conviction rate based on post-conviction DNA testing of sample of cases); J. Gould and R. Leo Centennial Symposium: A Century of Criminal Justice : II 'Justice' in Action: One Hundred Years Later: Wrongful Convictions After a Century of Research , 100 J. of Crim. L. and Criminology (2010) (previous estimates of wrongful convictions suggested upper bound of 3-5%) D. Michael Risinger, *Innocents Convicted: An Empirically Justified Factual Wrongful Conviction Rate*, 97 J. Crim. L. & Criminology 761, 762 (2007) (defending a 3 to 5% wrongful conviction rate).

[104] Murder Accountability Project, http://murderdata.blogspot.com/p/about.html, checked on April 7, 2015 (noting that rate at which police clear homicides through arrest has steadily declined and that every year more than 5000 killers are not arrested).

[105] Sir William Blackstone, COMMENTARIES ON THE LAWS OF ENGLAND (1765).

[106] CHARLES PERROW, NORMAL ACCIDENTS: LIVING WITH HIGH-RISK TECHNOLOGIES (1984) (noting importance of using uncoupled systems to reduce accident risk).

[107] See National Institute for Standards and Technology, *Speaking of Error in Forensic Science*, September 5, 2017 available at https://www.nist.gov/news-events/news/2017/09/speaking-error-forensic-science (noting that forensic science field has historically not been willing to discuss errors or admit to making any).

probative weight of forensic evidence as well as its limits and reasons for its absence. In practice, prosecutors and law enforcement believe that jurors harbor unrealistic beliefs about it and that testing is often conducted to address these unrealistic beliefs rather than to actually generate probative evidence. In fact, some of our results may be best understood as a result of this reverse causation. Rather than forensic science shaping the subsequent investigation, arrest rates, and charging decisions, forensic evidence is often only tested if authorities have an otherwise strong case. This use of forensic evidence nullifies one of its chief advantages – its comparative independence from the human failings of a traditional police investigation and its potential to reduce erroneous inclusions and exclusions.

Many other professions and industries (e.g. manufacturing, aviation and medicine) have focused on designing systems with independent decoupled processes to reduce the chance that the inevitable human lapse will lead to a grave error in the outcome of the system.[108] Decoupling reduces the interdependencies in the system and the effect of a single mistake on the outcome of the system. Forensic science has the potential to be such a critical independent process for the criminal justice system and thereby improve reliability and reduce errors -- both unsolved crimes and wrongful convictions. But our research suggests that its use will need to change and increase to fulfill this promise.

[108] See, e.g., ATUL GAWANDE, THE CHECKLIST MANIFESTO: HOW TO GET THINGS RIGHT (2009) (calling for the use of checklists to minimize human error in medicine and chronicling other attempts to do the same); James M. Doyle, *Learning from Error in American Criminal Justice*, 100 J. CRIM. L. & CRIMINOLOGY 109 (2010) (calling for criminal law to view wrongful convictions as organizational accidents and to create, like the fields of medicine and aviation, a culture of safety); James M. Anderson & Paul Heaton, *How Much Difference Does the Lawyer Make? The Effect of Defense Counsel on Murder Case Outcomes,* 122 YALE L. J. 154, 208-212 (2012) (calling for making process of criminal defense less dependent upon the characteristics of the individual professional and more robust to inevitable human error.)