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Information Technology, Organization, and Productivity in the Public Sector: Evidence from Police Departments

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We examine the relationship between information technology (IT), productivity, and organization using a new panel data set of police departments that covers 1987–2003. When considered alone, increases in IT are not associated with reductions in crime rates, increases in clearance rates, or other productivity measures, and computing technology that increases reported crime actually generates the appearance of lower productivity. These results persist across various samples, specifications, and IT measures. IT investments are, however, linked to improved productivity when they are complemented with particular organizational and management practices, such as those associated with the Compstat program.

I. Introduction

Public sector organizations are important consumers of information technology (IT), primarily because many public functions, such as revenue

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management, crime fighting, and education, are essentially information-processing tasks.[1] Thus, we might expect large changes in the cost of processing information to have an important impact in public organizations. Despite a growing literature on the effects of the spread of IT on firms, there is limited evidence regarding the extent to which IT is related to productivity and organization in the public sphere. In this article, we study the relationship between IT and the effectiveness of public agencies using a sample of police departments that covers 1987–2003, which we have merged with local data on crime and other productivity measures.

Our article contributes to large bodies of research on the skill content of technological change and the interrelationships between IT, work organization, and productivity. We extend previous research by focusing on public sector entities and constructing a data set that provides repeated observations of agency-level IT, organizational structure, and productivity over a 16-year period that features enormous growth in IT. Some previous studies of IT cannot examine organizational factors because they use the industry or a single firm as the unit of analysis (e.g., Berman, Bound, and Griliches 1994; Autor, Katz, and Krueger 1998; Stiroh 2002; Aral, Brynjolfsson, and Van Alstyne 2007) or because they rely on a cross section of firms (e.g., Bresnahan, Brynjolfsson, and Hitt 2002; Acemoglu et al. 2007).[2] Others do follow individual firms over time but either have no data on IT adoption (e.g., Berman et al. 1994; Rajan and Wulf 2006) or have no information on organizational change (e.g., Lehr and Lichtenberg 1999; Brynjolfsson and Hitt 2003). A more limited number of papers provide firm-level evidence on the evolution of IT, skill usage, and organizational change, including those by Caroli and Van Reenen (2001), who report data for the 1980s in the United Kingdom and for the early 1990s in France; Doms, Dunne, and Troske (1997), who study a panel of manufacturing firms between 1987 and 1992; and Lynch (2007), who examines a panel of U.S. firms observed in both 1994 and 1997. Our panel is longer, and our measures of productivity change are likely more precise in that they are not subject to the usual quality biases. None of these studies examines public sector entities.

Similar to our approach in their use of microdata, panel evidence, and precise measures of technology are the approaches of Athey and Stern (2002) and Hubbard (2003). Athey and Stern (2002) study the impact of emergency-response technology adoption on response outcomes. They do not have organizational and skill measures beyond the job design

[1] Following Arrow (1974), a large body of literature studies organizations as information-processing and problem-solving institutions—e.g., Radner and Van Zandt (1992), Bolton and Dewatripont (1994), and Garicano (2000).

[2] This article has panel data on IT and inputs but has cross-sectional information for organizational variables.

changes implicitly involved in the adoption of emergency medical dispatching (EMD) protocols. Thus, while they can study some aspects of the complementarity hypothesis, they are restricted by the available data in ways we are not.[3] Hubbard (2003) studies the productivity (capacity utilization) impact of onboard computers in trucking. He also is able to study the organizational impacts of these changes but has no evidence on changes in skill demand. Angrist and Lavy (2002) and Goolsbee and Guryan (2006) study the impact of the use of computers on educational outcomes. Both find an impact insignificantly different from zero, similar to our initial finding below. However, neither of these two papers analyzes complementary changes in teaching methods, job design, and organization.

We start by analyzing the relationship between computerization and productivity. Our basic empirical strategy compares productivity across departments that adopted differing levels of computing technology and controls for city size and other characteristics, including unobserved agency effects. General IT adoption alone is not associated with improvement in the productivity of police work as measured by clearance rates and is actually associated with increases in crime rates. We carefully analyze the generality of these results and find them robust to alternative samples (by period, early adopters, growing vs. nongrowing cities, etc.) and specifications of the IT measure.

Given the widespread adoption of IT by police agencies during our sample period, the fact that IT generates few productivity benefits seems surprising. The remainder of our article focuses on interpreting these results. We first examine whether our findings represent measurement error or misspecification of the dynamic structure of the relationship between IT and productivity but find little support for either hypothesis. Future IT adoption is not associated with current crime rates, which suggests that poor performance does not induce technology expansions. We next examine whether IT may affect other margins of productivity, such as conviction rates or officer safety. Although IT is associated with modest improvements in safety, these effects do not appear sufficiently large to explain substantial IT investments.

We also study whether our findings reflect (previous) mismeasurement of crime: although some information technologies, such as those that identify crime "hot spots," should improve deterrence, others could actually worsen crime statistics. For example, improvements in crime reporting will increase recorded crime rates. We test for heterogeneous effects of different technologies by simultaneously regressing offending rates on five distinct IT measures: computer use for record keeping, crime

[3] They do not find evidence in favor of the complementarity between technology (smart emergency-dispatch 911 technology) and the adoption of EMD protocols.

analysis, investigation, dispatch, and manpower. We find that offense reports increase by 10% when computers are used for record keeping and that these effects occur for crimes that are more likely to suffer from underreporting, such as larceny, rather than for those that are typically reported, such as homicide and motor vehicle theft. However, our estimates provide little evidence of an ameliorative effect of IT on crime, even when the consequences of improved measurement are taken into account.

In the private sector context, some researchers have argued that a barrier to the success of IT may be the need to implement IT together with particular organizational changes, an application of the complementarity hypothesis first advanced formally by Milgrom and Roberts (1990).[4] Although IT by itself may have little impact, its impact may be substantial when it is introduced within the context of an organizational and human resource system designed to take advantage of it. In the specific context of police work, the complementarity hypothesis takes one very salient form: Compstat. The system of practices summarized by this name was initially introduced in the New York Police Department (NYPD) by Police Commissioner William Bratton under Mayor Rudolph Giuliani's leadership and then spread throughout the country. The program aimed to combine real-time geographic information on crime with strong accountability by middle managers in the form of daily group meetings, geographic resource allocation, and data-intensive police techniques. The program was widely credited in the press and by policy makers with playing a substantial role in the recent precipitous drop in crime experienced by some cities.[5]

We provide several pieces of evidence consistent with the complementarity hypothesis. We first demonstrate that IT adoption is associated with a variety of organizational changes within a department, including an expansion of personnel (primarily in technical support roles as opposed to field operations), an increased use of special units, and enhanced training and educational requirements. Thus, departments that expanded IT use also modernized in other important ways. We next identify agencies that simultaneously implemented high levels of IT, specialization, and edu-

[4] Brynjolfsson and Hitt (2000) review this literature. In their analysis of modern manufacturing, Milgrom and Roberts (1990) argue that, given the existence of complementarities among organizational practices, a range of organizational choices may have to be altered together for a particular technological advance to improve efficiency. In the presence of complementarities, success is not "a matter of small adjustments, made independently at each of several margins, but rather involve[s] substantial and closely coordinated changes in a whole range of the firm's activities" (1990, 513).

[5] Some research has disputed the claim of a large effect of Compstat. See, e.g., Levitt (2004) and Rosenfeld, Fornango, and Baumer (2005).

cation, which we term "modern" agencies. In panel regressions that control for our underlying organizational and IT measures, we demonstrate that agencies implementing this combined set of practices experienced statistically significant drops in crime rates.

To further test the complementarity hypothesis, we study the impact of IT when it is adopted together with management techniques characteristic of Compstat, including skilled officers, new problem-solving techniques, extensive use of "output" information in evaluation and deployment of officers, and a geographic-based structure.[6] Although the data available for testing this hypothesis are much shorter and more limited (questions on these types of practices were introduced in the survey only in 1997), they clearly endorse this hypothesis. We find that crime clearance rates were an average of 3.2 percentage points higher in agencies that implemented this integrated set of practices. Similarly, crime rates are negatively associated with Compstat use. Moreover, the individual practices composing Compstat have no independent ameliorative impact on crime levels or clearance rates.[7]

We thus conclude that IT may improve police productivity, but such improvements occur only when IT is introduced in conjunction with certain organizational practices oriented to take advantage of new data availability. More generally, our results demonstrate that many of the forces identified in the labor literature on IT in profit-maximizing firms—such as IT-related shifts in demand for skilled labor, heterogeneous productivity effects of IT, and IT/management-practice complementarities—are also apparent in public sector organizations.

II. Data Description

The data are drawn from the Law Enforcement Management and Administrative Statistics (LEMAS) series, a triennial survey of law enforcement agencies in the United States that covers the years 1987–2003.[8] Although it was not specifically designed as a longitudinal survey, the broad coverage of the survey makes it possible to identify numerous agencies

[6] Our approach is similar to that of Ichniowski, Shaw, and Prennushi (1997), who study complementarities among human resource management practices and their impact on productivity. IT is not, however, a focus of their study.

[7] Again, the causal interpretation of this increase must be qualified. If a system of complementary changes must be undertaken, the fact that some departments choose not to undertake these changes may reflect some omitted variable, such as the quality of management of the department, in which case the 3.2-percentage-point increase is biased upward. This problem is common, to a large extent, to all of the literature on organizational change (see, e.g., Ichniowski and Shaw, forthcoming).

[8] The 1996 survey was conducted in 1997, and an additional survey was conducted in 1999. Survey response rates ranged from 90%–98%.

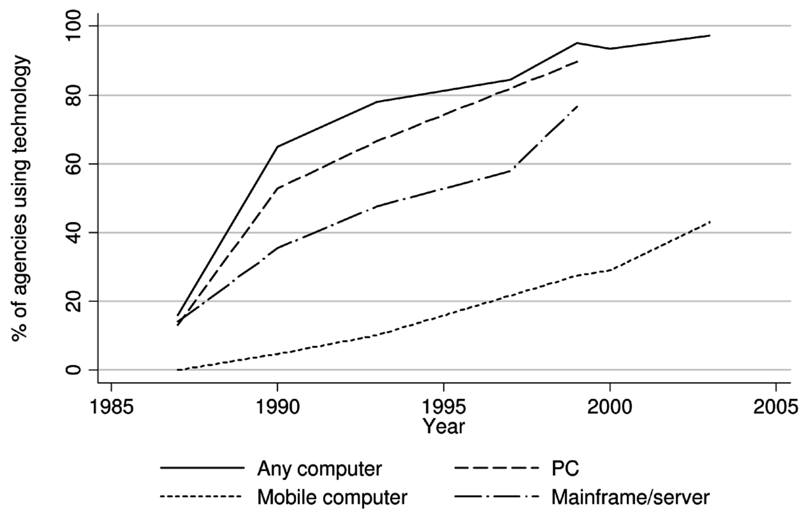

FIG. 1.—Information technology use by computer type

at multiple points in time.[9] The surveys provide rich data on a wide variety of police operations, including shift scheduling, equipment usage, agency structure and functions, officer compensation, and administrative policies. To supplement the LEMAS data, we have matched the surveyed agencies with annual arrest and offense data from the Federal Bureau of Investigation's Uniform Crime Reports (UCR) and, where possible, place-level demographic data from the census.

One of the strengths of this data set is that it contains questions on a variety of different types of IT use and covers a period of enormous IT expansion. Figures 1–3 plot aggregate trends in IT use by police agencies. Figure 1 details the use of different types of information technologies, including personal computers (PCs), mobile data terminals (typically used by officers to access vehicle, criminal background, or other information while in the field), and mainframes and servers. In 1987, fewer than 20% of the surveyed agencies used any computers, but over the next 12 years computer use showed substantial increases, with PC use growing more rapidly than that of more specialized technologies. By the end of the sample, over 90% of responding agencies reported IT use. The large increase in mainframe and server use near the end of the sample is likely

[9] All state police agencies and all agencies with 100 or more officers are automatically sampled, with probability sampling for the remaining agencies. In each year, roughly 3,000 of the approximately 19,000 U.S. law enforcement agencies are represented.

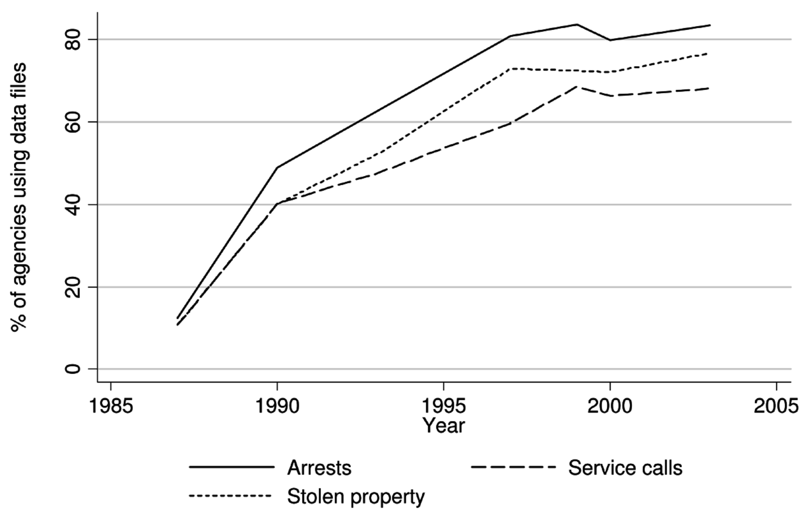

FIG. 2.—Data availability by type

attributable to the increased importance of the Internet in the latter half of the 1990s.

Figure 2 details the use of computerized data files by function. Growth trends in data use for arrests, service calls, and stolen property were comparable through the entire sample. Figure 3 demonstrates a significant asymmetry in IT adoption according to agency size. A substantial proportion of the largest police agencies already had computing technologies by 1987. In stark contrast, only two of the over 2,200 departments with 100 or fewer employees in 1987 reported using computers. Between 1987 and 1990, there was widespread adoption of computers by midsize agencies, and the smallest agencies lagged behind until the final years of the sample.

The patterns in figures 1–3 suggest that much of the growth in IT across police agencies may have been driven by the declining prices and improvements in technology experienced during the 1990s. Initially, when IT was relatively expensive, only larger agencies were able to make the substantial investments required to obtain computer systems. As the price of IT fell, computing technology became more readily available to smaller agencies and could be used for a wider variety of tasks.

Our preferred measure of computer usage is a computer index constructed as the proportion of nine computer/data functions present in an agency in a given year.[10] The advantage of this index relative to simple

[10] The nine functions we include are computer use for crime analysis, investigation, and dispatch and data record use for arrests, service calls, criminal histories, stolen property, traffic citations, and warrants.

FIG. 3.—Information technology use by agency size

dichotomous IT measures is that it captures not only the existence of IT within an organization but also the degree to which IT is used to perform disparate tasks. During our sample, the computer index increased from an average of 0.11 in 1987 to 0.64 in 2003.

Table 1 provides summary statistics describing the measures of output, organizational structure, and worker skill that we employ in our analysis. The varying number of observations reflects the fact that not all survey items are available in all years and that UCR and census data were not available for all agencies. In total, approximately 8,600 police agencies are represented at some point in the sample, with over 1,800 agencies registering observations in four or more sample years. Many of the police agencies in the sample are county or city agencies within moderately sized jurisdictions, but university, state, and large city police departments are also represented. The areas represented are slightly poorer, less educated, and less diverse than the overall United States, which likely reflects, in part, the higher sampling rates of large urban agencies.

III. Patterns in IT Adoption and Productivity

In this section, we estimate the relationship between IT adoption and improved police productivity, as measured by case solution rates and crime reduction. Although some authors have argued that a primary role of IT in police organizations is to improve police problem solving (Brown and Brudney 2003), there is little empirical evidence connecting IT use to improved enforcement. We measure case solution by using crime clearance

Table 1
Summary Statistics

Measure	*N*	Mean	SD	Minimum	Maximum
Computerization:					
Computer index	19,458	.521	.370	0	1
PC use	13,720	.638	.481	0	1
Computerized record keeping	16,294	.632	.482	0	1
Productivity:					
Total crime clearance rate	14,793	.229	.164	0	1.083
Violent crime clearance rate	13,920	.559	.272	0	1.095
Property crime clearance rate	14,525	.188	.147	0	1.083
Total offense rate	14,773	.034	.033	0	.496
Violent offense rate	14,781	.004	.006	0	.203
Property offense rate	14,777	.030	.030	0	.495
Officers killed or assaulted	9,458	63.8	290	0	9,024
Felony conviction rate	175	.743	.138	.377	.968
Departmental size and complexity:					
Number of employees	19,893	197	959	.5	55,929
Number of special units	4,889	4.48	2.32	0	8
Number of agency functions	14,089	3.48	1.80	0	11
Organizational levels	15,216	2.82	.50	1	3
Total written directives	14,639	3.95	2.03	0	6
Departmental organization:					
% officers with arrest powers	19,893	.785	.171	0	1
% field operations staff	5,549	.606	.193	.003	.995
% technical support staff	7,764	.120	.117	0	.877
Worker skill and training:					
College requirement for new officers	16,164	.128	.334	0	1
Hours of training for new officers	15,712	669	472	0	2,080
Demographic characteristics:					
Total population	19,529	225,608	1,282,226	0	35,484,453
% black	19,362	.103	.159	0	1
% Hispanic	19,362	.066	.133	0	1
Poverty rate	19,362	.137	.082	0	.657
Median household income	19,362	39,173	15,743	4,208	202,242
% high school graduate	19,362	.763	.112	.203	1.000
% college graduate	19,362	.200	.124	0	.883

Sources.—Computerization and other organizational measures are taken from the Law Enforcement Management and Administrative Statistics survey. Clearance rates and offense rates are from the Federal Bureau of Investigation's (FBI) Uniform Crime Reports data. The numbers of officers killed or assaulted comes from the FBI's Law Enforcement Officers Killed and Assaulted data. Conviction rates come from the Bureau of Justice Statistics' State Court Processing Statistics data. Demographic information corresponds to the area covered by each agency and is taken from the 1990 and 2000 censuses, with linear interpolation across years.

rates, which approximate the probability that an offender will be arrested conditional on committing a crime.[11] To examine the deterrent aspect of

[11] The clearance rate is the number of crimes that are "cleared" divided by the total number of offenses reported to police. Crimes are typically cleared through an arrest, but clearances can also occur for other reasons (such as the death of

enforcement, we also consider offending rates per population as dependent variables. To examine possible asymmetries in the usefulness of IT across crimes, we examine arrests made for violent crimes separately from arrests made for property crimes. Although arrest and offending measures are indicators of enforcement output, they must be viewed with particular caution, given that they capture only certain dimensions of enforcement. Simple arrest and offending measures fail to account for conviction rates, elimination of concentrated areas of crime, response speed, and other factors that may enter into the objective functions of police departments.

For our basic analysis, we use ordinary least squares (OLS) regressions that include year and agency fixed effects. Including agency fixed effects allows us to identify the relationship between IT and productivity while we control for unobserved factors specific to an agency that are unchanging over time, such as geography. We thus compare productivity across agencies with differential growth in IT over the sample period. In some specifications, we include controls for demographics, time trends, or other factors that may affect our outcomes of interest. If differential acquisition of IT is driven by factors exogenous to the agency, such as variations in the cost of technology over time and place, the OLS coefficients would reflect an effect of IT on productivity. However, it seems likely that omitted factors may explain some of the associations we find using OLS, an issue we return to below.

Table 2 reports our results. Column 1 of the table reports OLS estimates with year and agency fixed effects, and column 2 adds controls for agency size and the demographics of the area served by the agency. The data do not suggest that agencies that substantially increased IT over the sample period had superior improvements in clearance rates compared with those that made little IT adjustment. Relative to the mean clearance rate of 0.23, the estimated associations are small and are estimated fairly precisely. Estimates for offending rates, on the other hand, are positive and statistically significant for total and property crime, although the inclusion of state-specific time trends (col. 3) weakens the relationship somewhat. For property crime, an increase of 0.53 in the computer index is associated with a 0.0017-percentage-point, or roughly 5%, increase in the offending rate.

One concern with our index is that, in the presence of measurement error, our estimated effects may be attenuated. Instrumenting the index by using additional measures of IT intensity offers one method for minimizing such biases. In column 4, we report instrumental variables (IV) estimates in which we instrument for the IT index, using a set of indicators

the suspect). Because arrests can occur for crimes committed in prior years, clearance rates can be greater than 1. For a more detailed discussion of the use of clearance rates in crime research, see Skogan and Frydl (2004, 160).

Table 2
Relationship between Information Technology Use and Productivity

Productivity Outcome	(1)		(2)		(3)		(4)	
Crime clearance rate:								
All crime	.00147	(.00588)	−.00037	(.00603)	−.00141	(.00595)	−.00577	(.0188)
Violent crime	.0131	(.0104)	.0109	(.0105)	.0140	(.0103)	−.00555	(.0313)
Property crime	.00339	(.00508)	.00289	(.00519)	−.00451	(.00514)	.00841	(.0162)
Offense rate:								
All crime	.00374***	(.00077)	.00326***	(.00075)	.00264***	(.00073)	.00886***	(.00208)
Violent crime	.00019	(.00014)	.00015	(.00014)	.00005	(.00014)	.00157**	(.00072)
Property crime	.00355***	(.00070)	.00312***	(.00069)	.00260***	(.00065)	.00729***	(.00183)
Include year and agency fixed effects?	Yes		Yes		Yes		Yes	
Include additional controls?	No		Yes		Yes		Yes	
Include state trends?	No		No		Yes		No	
Instrument to account for measurement error?	No		No		No		Yes	

Note.—This table reports regressions of measures of police productivity on a computerization index. Each entry represents a coefficient estimate from a separate regression where the listed productivity outcome is the left-hand-side variable and controls are included as specified in the bottom rows of the table. All specifications include a full set of year and police agency fixed effects. Column 2–4 regressions include the percentage black, percentage Hispanic, and per capita income of the area covered by the agency as additional controls. The arrest regressions also include agency size deciles interacted with the log number of agency employees and the log population covered by the agency as additional controls. The offense regressions include indicators for deciles of resident population interacted with the log population and the log number of agency employees as additional controls. Column 3 includes state-specific yearly time trends as controls, and col. 4 instruments the information technology index by using indicators for PC, mainframe, and minicomputer use. The regressions in cols. 1–3 have approximately 12,000 observations, and those in col. 4 have approximately 7,000 observations. Standard errors clustered on agency are reported in parentheses.

** Significant at the two-tailed 5% level.

*** Significant at the two-tailed 1% level.

for whether an agency reported using PCs, mainframes, and minicomputers.[12] For both productivity measures, the coefficients are larger after IV estimation, which is consistent with the presence of measurement error, but our conclusion that IT does not affect clearance rates but is associated with increased offending remains intact.[13]

These results indicating a null productivity improvement from IT are robust across different specifications, which are presented in table 3. The first set of specifications examines alternative methods for measuring IT. Our IT measure is designed to capture the general expansion of technology within a department and makes use of those measures that are available in all the years of the survey. Ultimately, however, there is no single appropriate way to measure IT intensity, and so we examine whether alternative measurement approaches yield similar conclusions. Specification 1 substitutes our IT index with an alternative index that weighs the computer-use variables at 25% each and the data-use variables jointly at 25%; this index attempts to recognize the possibility that increasing data availability represents less of an investment in IT than does expanding the types of activities for which IT is employed. Specifications 2 and 3, respectively, use a simple 0–1 indicator for the presence of PCs and an indicator for the presence of any type of computing technology within the department as IT measures. In all three cases, we obtain coefficient estimates of similar sign and statistical significance to those reported in table 2.

The fourth specification measures IT by using the number of computers in use in an agency per employee. This is a highly intuitive measure of IT intensity, but because questions about the number of computers in use were included in only a single survey (1999), it requires us to restrict our sample to one year and to identify the relationship between IT and productivity cross-sectionally. However, even using this somewhat different IT measure and different identification approach, the results accord with our baseline findings that increased IT intensity is not associated with improvements in case solution rates but is associated with higher offending rates.

The next specifications in table 3 test alternative samples. Specification 5 limits the analysis to agencies that reported some IT use in their first year in the sample. This specification examines whether the observed effects can be attributed to changes in IT intensity as opposed to simple adoption of any IT. Specifications 6 and 7, respectively, limit the sample

[12] These indicators are not included as part of our IT index because they are not available after 1999, forcing us to omit 2 years of sample data in the IV analysis.

[13] As expected, the unreported first-stage coefficients of the included instruments are positive, and the Wald statistics on the instruments are substantially above the weak instrument thresholds in Stock and Yogo (1995).

Table 3
Robustness Checks of the Information Technology and Productivity Relationship

Dependent Variable	Clearance Rate: Total	Clearance Rate: Violent	Clearance Rate: Property	Offense Rate: Total	Offense Rate: Violent	Offense Rate: Property
Alternative IT measure:						
1. Alternate computer index	−.00331 (.00569)	−.00776 (.00959)	.00161 (.00497)	.00259*** (.00064)	.00016 (.00012)	.00243*** (.00059)
2. PC indicator as IT measure	.00581 (.00623)	.0124 (.0112)	.00464 (.00526)	.00256*** (.00062)	.00041*** (.00013)	.00215*** (.00057)
3. Indicator for any type of computer as IT measure	−.00210 (.00755)	.0223 (.0135)	.00223 (.00697)	.00484*** (.00077)	.00047*** (.00014)	.00435*** (.00071)
4. Computers per employee as IT measure (1999 only)	.00105 (.0104)	−.00406 (.0184)	.00645 (.00980)	.01560*** (.00188)	.00142*** (.00028)	.01420*** (.00173)
Alternative sample of agencies:						
5. With IT in 1987	−.00202 (.00793)	.0126 (.0138)	−.00033 (.00672)	.00124 (.00098)	−.00012 (.00021)	.00137 (.00089)
6. With <25 employees	.00737 (.0154)	−.0184 (.0332)	.0134 (.0143)	−.00179 (.00127)	.00012 (.00024)	−.00190 (.00119)
7. With >100 employees	.00315 (.00704)	.0104 (.0115)	.00489 (.00576)	.00274** (.00109)	.00004 (.00020)	.00270*** (.00100)
8. In shrinking cities	−.00085 (.0137)	.0129 (.0245)	.0104 (.0126)	.00316 (.00161)	.00020 (.00029)	.00296** (.00147)
9. In cities with stable populations	−.0105 (.00898)	.00798 (.0158)	−.00656 (.00805)	.00310*** (.00097)	.00032 (.00016)	.00278*** (.00090)
10. In midsize cities	.00050 (.0136)	.0124 (.0292)	.00595 (.0112)	.00792*** (.00221)	.00110*** (.00037)	.00682*** (.00199)
Alternative specification:						
11. Control for equipment budget	−.0110 (.0105)	.00875 (.0169)	.00040 (.00756)	.00590*** (.00136)	.00044 (.00025)	.00547*** (.00125)
12. Control for equipment and salary budget	−.00864 (.00972)	.0128 (.0162)	−.00110 (.00714)	.00481*** (.00127)	.00010 (.00028)	.00471*** (.00115)
13. Omit 1987	−.00698 (.00744)	−.00523 (.0126)	−.00126 (.00636)	.00286*** (.00085)	−.00006 (.00020)	.00292*** (.00076)
14. Limit to agencies with four or more observations	−.00337 (.00701)	.00806 (.0116)	−.00071 (.00584)	.00374*** (.00091)	.00008 (.00017)	.00366*** (.00082)

Note.—This table reports regressions analogous to those presented in col. 2 of table 2, employing alternative specifications. See notes for table 2. Each entry reports coefficient estimates from a unique regression. Specification 1 substitutes an information technology (IT) index weighing the three computerization functions at 25% and the remaining six data functions at 25% in place of the basic IT index. Specification 9 limits the analysis to cities with less than 10% population change during the sample period. Specification 10 limits the analysis to agencies with populations between 80,000 and 100,000.

** Significant at the two-tailed 5% level.

*** Significant at the two-tailed 1% level.

to the smallest and largest police departments. There is less evidence of crime increases among agencies with preexisting IT and small agencies, but for these samples there remains little evidence of IT-related improvements in productivity. The next rows of table 3 report additional checks of the hypothesis that our results are driven by general changes associated with population growth. Specification 8 limits the analysis to only places in which population fell over the course of the sample. Specification 9 includes only agencies in areas in which the population changed by 10% or less. Specification 10 builds a sample of agencies in comparably sized areas by considering only agencies with base populations between 80,000 and 120,000. Areas with declining or stable populations yield point estimates of similar magnitude to the universe of agencies. Thus, it does not appear that community growth is driving both IT acquisition and changes in crime.

Crime patterns may affect the availability of financial resources within an agency, and agencies with greater financial resources may be more likely to purchase IT. Specification 11 reports regressions that attempt to flexibly control for differences in resource availability by interacting the log of equipment expenditures with indicators for deciles of equipment expenditure.[14] Specification 12 analogously controls for combined equipment and salary expenditures. Although these controls do not perfectly capture resource differences across agencies, encouragingly, their inclusion does not substantively alter our results. Specification 13 omits 1987 from the sample to assess whether the results are driven mainly by the large increase in computer use that occurred between 1987 and 1990, while specification 14 improves the panel quality of the data by limiting the analysis to agencies observed in four or more time periods. Neither modification yields appreciably different conclusions. Overall, the basic results appear fairly robust to sample and specification changes.

IV. Interpreting the Relationship between IT and Productivity

Given the positive association between IT and firm productivity documented by past researchers (e.g., Lichtenberg 1995; Black and Lynch 2001) and the widespread use of IT in modern police departments, our finding that computers contribute little to productivity may seem somewhat surprising. The remainder of this article explores potential explanations for this somewhat counterintuitive finding.

A. Model Misspecification

One possibility is that IT does in fact improve clearance rates or decrease offending but that misspecification of our regression equation biases

[14] Unfortunately, information on annual expenditures on equipment is available only from 1987 to 1997, and the value was estimated by some agencies.

estimates of this relationship. Our specifications above attempted to account for measurement error and bias arising from omission of agency resources. An additional concern is that casuality may run in reverse if agencies adopt IT in response to negative trends in performance. Under this scenario, simple mean reversion might bias our estimates of the relationship between IT and productivity—a form of the "Ashenfelter dip."[15] Given that such a mechanism is likely to generate upwardly biased estimates yet our estimates are close to zero, we suspect that such biases are small in our setting. However, we can directly test for this phenomenon by replicating our analysis and including leads in the computer index as additional explanatory variables. Any tendency toward decay in our dependent variables prior to the introduction of IT should be manifest in negative coefficients on these leads.

The first two columns of table 4 demonstrate that, for our outcome measures, there is little evidence of an Ashenfelter dip; none of the coefficients on leads is statistically different from zero, and there are equal numbers of positive and negative point estimates. The coefficients on the index itself, in contrast, typically maintain the same sign and significance as those in the baseline.[16]

Another potential explanation for the apparent lack of a relationship between IT and outcomes is that IT improves policing only after an initial learning period. The second specification in table 4 tests for this possibility by including a lag of the computer index as an additional regressor. Given the 3-year separation between most surveys, it seems likely that any delayed benefits of IT implementation would be captured by this lagged term.[17] The coefficients on the lagged term, however, are generally negligible and are statistically indistinct from zero.

Failure to account for dynamic dependence of our dependent variables may also lead to biased estimates of the relationship between IT and productivity (Nickell 1981). In column 3 of table 4, we report estimates that account for the possibility that our crime measures follow a first-order autoregressive process; these estimates are obtained using the generalized method of moments approach of Arellano and Bond (1991). Consistent with our previous results, we find no evidence of an improvement in case solution rates following an increase in IT. There is less evidence that IT is associated with higher offending in this specification.

[15] Ashenfelter (1978) observed that participants in training programs had unexplained drops in pay just before enrollment.

[16] In an unreported analysis, we also examined whether there were differential trends in IT adoption for agencies with large amounts of litigation in 1987, which we take as a proxy for poor management. Trends were comparable in these agencies.

[17] In unreported regressions, we include an additional lag and obtain similar results.

Table 4
Dynamic Tests of the Information Technology and Productivity Relationship

	Lead Specification		Lag Specification		
Productivity Outcome	Current Index	Lead of Index	Current Index	Lag of Index	Arellano-Bond
Crime clearance rate:					
All crime	−.0118 (.00852)	−.00143 (.00719)	.00074 (.00810)	.00281 (.00726)	−.00346 (.00925)
Violent crime	.00600 (.0136)	.0246 (.0143)	−.00508 (.0137)	−.0178 (.0134)	−.0229 (.0156)
Property crime	−.00735 (.00688)	−.00165 (.00605)	.00141 (.00697)	.00277 (.00604)	.00625 (.00793)
Offense rate:					
All crime	.00319*** (.00111)	.00137 (.00097)	.00158 (.00097)	.00103 (.00080)	.00085 (.00090)
Violent crime	−.00016 (.00027)	−.00006 (.00020)	.00010 (.00017)	.00028 (.00016)	.00025 (.00014)
Property crime	.00335*** (.00100)	.00142 (.00089)	.00148 (.00088)	.00075 (.00073)	.00067 (.00082)

Note.—This table replicates the regressions from col. 3 of table 2, allowing for more complex dynamic relationships between variables. See notes for table 2. Within a specification, each row reports coefficient estimates from a separate regression. The first specification includes one additional lead of the computer index, and the second specification includes a single additional lag as explanatory variables. The final specification models the productivity outcome as a first-order autoregressive process and obtains consistent estimates of the impact of information technology using the generalized method of moments methodology of Arellano and Bond (1991).

*** Significant at the two-tailed 1% level.

Clearly, it is possible that these estimates are affected by other forms of endogeneity, but our high level of geographic disaggregation and relatively long time series make it difficult to identify credible instruments. In general, however, we might expect that many sources of endogeneity would lead to upwardly biased estimates of the effect of IT on productivity, which leads us to conclude that misspecification is unlikely to explain our findings.

B. General Public Sector Inefficiencies

Investments in IT may be subject to the same inefficiencies as other types of public sector investments, a possibility consistent with some past findings regarding public sector IT. Goolsbee and Guryan (2006), for example, find that more access to the Internet by schools does not measurably increase student achievement. Angrist and Lavy (2002) obtain a similar result for general computer use in Israeli schools. Berger and Kichak (2004) and Garg et al. (2005) argue that widespread adoption of computerized physician ordering systems in the health care sector has generated ambiguous productivity benefits. IT in police departments may be subject to the same effectiveness-limiting forces noted in these other settings. Indeed, several case studies of police computer use, such as those by Manning (2001) and Ratcliffe (2002), demonstrate that significant investments may yield systems with poor operational characteristics and limited acceptance.

However, the widespread adoption of IT and relatively large investments made by some cities remain difficult to explain if IT truly has no productivity benefits. For example, Boston and Detroit each spent over $20 million to implement new computer systems in the late 1980s, or roughly $20 and $40, respectively, on a per capita basis (Manning 1992). By way of comparison, a report by the General Accounting Office (2005) evaluating a large federal hiring program estimates that an additional $10 per capita spending on police personnel decreases crime by 6%. Thus, while standard public sector inefficiencies may to some extent explain our findings, it remains surprising that many departments would invest in IT, given that seemingly more productive personnel investments were also available.

C. Improved Measurement

One potential explanation for these results is that our index, which provides a fairly general measure of IT intensity, could mask heterogeneous effects of different information technologies on our enforcement outcomes. For example, offenses might be higher in places with more computers simply because officers may be more willing to file police incident reports when filing can be done using computers instead of by hand. Other technologies, such as technologies that improve officer deployment, may at the same time have a deterrent effect on crime.

To disentangle these potentially competing effects of IT, we exploit the detailed questions about IT use in the LEMAS survey. We measure IT use for report writing with an indicator for whether computers are used for record keeping. We separately employ measures of computer use for crime analysis, investigation, dispatch, and manpower allocation, to capture other IT functions within an agency.

Table 5 reports regressions that enter the record-keeping and other variables simultaneously as explanatory variables for offending rates.[18] For total offenses, the coefficient on the record-keeping computer-use indicator is positive and significant, which suggests that offense reports increase by 10% once computers are available for record keeping. The coefficients on other computer functions are smaller and insignificant. The additional columns replicate the analysis on different individual crimes to provide an additional test of our interpretation. Given the seriousness and rarity of homicide, homicide is almost universally reported. Similarly, because auto insurance companies typically require police reports in the case of motor vehicle theft, computerization is less likely to affect reporting for this crime. For these two crimes, the estimated coefficients on the record-keeping variable are statistically indistinguishable from zero. The point estimates on computer use for dispatch and manpower allocation are generally negative (albeit not significant), which suggests that technologies that assist in better deploying personnel to areas where crimes are likely may exert more of a deterrent effect.

Apparently, one explanation for the positive association between general IT and offending is that reporting technologies increase crime reports even if other technologies deter crime. However, this analysis does not allow us to reverse the conclusion that IT had limited impact on productivity. Adjusting the coefficients on the total offense rate in table 2 to account for improved reporting yields coefficients close to zero.[19] In addition, the relationship between IT and violent crime, which is less likely to be affected by reporting problems, is negligible. The estimated effects of deployment technologies are quite modest. Thus, the apparent absence of a positive impact of IT on police productivity is not a statistical artifact.

[18] Because the base offending rates differ substantially across crimes, these regressions are estimated in logs to improve ease of interpretation. Estimation in levels, as in table 2, generates the same conclusions.

[19] The proportion of agencies using computers for record keeping increased from 14% to 76% between 1987 and 2003. Based on the coefficients in table 5, this increase would translate to a 6%, or roughly 0.002-percentage-point, change in the offense rate, which should be subtracted from the coefficients on the total offense rate in table 2.

Table 5
Relationship between Offenses and Specialized Types of Information Technology

Explanatory Variable	Total		Homicide		Rape		Larceny		Vehicle Theft	
Computer used for:										
Record keeping	.0988***	(.0258)	.0375	(.0342)	.0438	(.0291)	.0501**	(.0222)	−.0177	(.0232)
Crime analysis	.0135	(.0192)	−.0219	(.0326)	.00227	(.0277)	.00401	(.0145)	.0199	(.0200)
Investigation	−.00505	(.0176)	.00587	(.0300)	.0535**	(.0261)	.0302**	(.0146)	−.0257	(.0187)
Dispatch	−.00456	(.0219)	−.0151	(.0291)	.00999	(.0284)	−.00403	(.0179)	.0183	(.0210)
Manpower allocation	−.0235	(.0181)	−.0133	(.0234)	−.00942	(.0212)	−.0164	(.0119)	−.00632	(.0165)
N	12,063		5,373		8,294		11,726		11,080	
R^2	.921		.892		.873		.953		.940	

Note.—This table reports regressions of the log offense rate reported by an agency on indicators for computerization of record keeping, crime analysis, investigation, dispatch, and manpower allocation. Each column reports the results of a separate regression, with the log offending measure used as the dependent variable indicated at the top of the column. The regressions include the percentage black, percentage Hispanic, per capita income, poverty rate, log number of agency employees, and population quintile indicators as additional controls. The regressions also include agency and year fixed effects. Standard errors clustered on agency are reported in parentheses. Regressions on offense rates measured in levels yield comparable conclusions.

** Significant at the two-tailed 5% level.

*** Significant at the two-tailed 1% level.

Table 6
Relationship between Information Technology and Other Productivity Measures

Outcome	(1)	(2)
Total assaulted or killed (N = 6,676)	−.0611 (.0382)	−.103*** (.0391)
Conviction rate (N = 175)	−.0263 (.0478)	−.0258 (.0493)
Include agency and year fixed effects?	Yes	Yes
Include additional controls?	No	Yes

NOTE.—The table reports panel regressions of the number of officers killed or assaulted (mean = 64) and the percentage of felony cases that resulted in conviction (mean = 0.74) on the computer index and additional controls. The unit of observation is an agency in a particular year, and each entry reports the results of a unique regression. The officer safety regressions are negative binomial regressions, and the conviction rate regressions are standard linear regressions. Column 1 regressions include year and agency fixed effects as additional controls. Column 2 regressions also control for average percentage black, percentage Hispanic, per capita income, poverty rate, and log population of the area covered by the agency. For officer safety, the col. 2 regression also controls for an indicator of whether the agency provides body armor to officers and the log number of agency employees interacted with deciles for the agency size. For conviction rate, the col. 2 regression controls for the log number of agency employees. Standard errors clustered on agency are reported in parentheses.

*** Significant at the two-tailed 1% level.

D. Missing Margins of Productivity

Although case solution and crime deterrence are arguably the two most important measures of police productivity, it is possible that the primary effect of IT is to improve police performance across other dimensions. In this section, we draw from ancillary data sources to examine whether IT is associated with improvements in officer safety or conviction rates. Unfortunately, we lack systematic data on other aspects of police performance, such as response time and community satisfaction, that may be important to departments and affected by IT.

We first consider the possibility that the effect of IT is to allow agencies to achieve the same clearance rates with less risk to officers. Such safety enhancements might occur through substitution away from street officers to administrative personnel or by providing information to officers that allows them to identify risky individuals and locations. To measure officer safety, we draw from the Law Enforcement Officers Killed and Assaulted (LEOKA) supplements to the UCR reports, which provide data on the number of officers killed and the number of officers assaulted, sorted by agency and year of occurrence.[20]

The top row of table 6 reports coefficient estimates from regressions relating the IT index to officer safety akin to those in table 2. Increases in the IT index are associated with decreases in the number of officers killed and in the number assaulted, although these effects are only statistically significant in the more expansive specification. By way of com-

[20] Officer deaths are fairly uncommon, with only 180 deaths across all agencies in all years of our sample.

parison, the estimated coefficient on an indicator for required use of body armor, which we include as one of the control covariates in column 2, is −0.110, with a standard error of 0.033. In other words, any safety benefits of IT adoption appear to be below those of body armor, which can be provided at a cost of roughly $500 per officer. Thus, while IT may improve safety, if these safety improvements are the major benefits of IT, they seem insufficiently large to justify the high cost of deploying an IT system.

We also constructed estimates of county-level conviction rates, using sample case data from 40 large counties collected on a biennial basis through the Bureau of Justice Statistics' State Court Processing Statistics (SCPS) program.[21] There are several limitations to these data, most notably the fact that only large counties are represented, which reduces the amount of available variation to identify the effects of IT, given that larger agencies are more likely to be early and intensive adopters of IT. Also, the SCPS data include only felony cases. However, they do provide a measure of the variation over time in convictions, which we can relate to adoption of IT by local law enforcement agencies.[22] The average conviction rate in our sample is 74%, but there is substantial variation across jurisdictions; some counties report conviction rates below 40% while others achieve convictions in over 95% of cases.

The second row of table 6 demonstrates that conviction rates are actually slightly lower in jurisdictions with high IT intensity, although this association is not statistically significant. Our evidence is thus not consistent with the notion that IT improves conviction rates. Although it ultimately remains possible that IT improves aspects of police productivity for which we lack data, missing productivity margins do not appear to provide a fully satisfactory explanation for the small impact of IT.

E. Complementarities

IT may increase police department productivity only in conjunction with a broader set of practices. Milgrom and Roberts (1990) proposed such a complementarity hypothesis in the manufacturing context, contrasting two basic systems, modern versus traditional manufacturing. Subsequent work, such as that by Bresnahan et al. (2002), Brynjolfsson and Hitt (2003), and Bartel, Ichniowski, and Shaw (2007), has identified empirical examples of complementarities between IT use and management practices.

[21] SCPS data are collected in even-numbered years; we averaged across adjacent years to construct measures for 1993, 1997, and 2003. Guilty pleas are considered convictions.

[22] Most large counties are dominated by a single major police agency that generates the bulk of court cases. Because we cannot identify the arresting police agency in the SCPS data, for the purposes of this analysis we consider only the largest police agency in each county.

As a first effort to examine complementarities, we estimate regressions similar to those presented in table 2 that use measures of the organizational characteristics of the department as dependent variables. The coefficients of these regressions measure the extent to which departments that expanded IT also implemented other organizational changes. We first consider the total number of sworn and nonsworn personnel as a measure of agency size. We next consider several measures of agency complexity, including the total number of special units, the number of agency functions, the number of hierarchical levels in the agency, and the number of written departmental policies.[23] We then consider work roles within the agency, examining whether IT adoption is associated with changes in the share of sworn officers, who are typically officers with arrest powers, or changes in the share of field or technical support personnel. Finally, we examine whether IT adoption is associated with the employment of more highly skilled workers, using the requirement that new officers have college experience and the number of required training hours as measures of worker skill. To account for the likelihood that organizational characteristics also vary with agency size, we flexibly control for workload in the personnel regressions and employee counts in the other regressions.

The top rows of table 7 demonstrate that IT use is positively and significantly associated with our measures of agency size and complexity. The coefficients on log employees suggest that IT expansions are associated with a 9%–27% increase in total personnel, even after agency workload is controlled for. IT is associated with increased specialization and the use of written directives as well. Finally, IT is not significantly associated with the number of hierarchical levels or functions after measurement error is accounted for.

Table 7 suggests that IT adoption has little connection to employment of sworn officers or field operations personnel. Increases in IT intensity are associated with a 7- to 20-percentage-point increase in staff assigned technical support roles. This increase is similar in magnitude to the in-

[23] Special units are smaller groups of officers with specific expertise and focus on a particular crime class or administrative program, such as gang investigations or school outreach. The special units that are consistent across sample years that we include are those for child abuse, community crime prevention, family violence, drug education, drunk driving, missing children, police/prosecutor relations, career criminals, and victim assistance. Agency functions include responsibilities such as accident investigation, court security, jail operations, and special investigations. We infer the number of hierarchical levels on the basis of whether separate salary ranges were reported for chiefs, sergeants, and junior-level officers in the survey. This is a somewhat crude proxy for the degree of hierarchy in the agency, given that many larger police agencies have substantially more than three administrative levels. The possible written policies are those governing general police conduct, the use of deadly force, the handling of domestic cases, and interactions with juveniles, the homeless, and the mentally ill.

Table 7
Relationship between Information Technology and Departmental Organization

Measure	(1)		(2)	
Departmental size and complexity:				
Log(number of employees)	.0881***	(.0105)	.241***	(.0335)
Number of special units	.445***	(.146)	.188	(.920)
Number of functions	.360***	(.0728)	−.0802	(.173)
Organizational levels	.0214	(.0129)	.0482	(.0325)
Total written directives	1.71***	(.0711)	4.93***	(.253)
Departmental organization:				
% officers with arrest powers	.00557	(.00475)	.00359	(.0148)
% field operations staff	−.00709	(.00790)	−.0712	(.0443)
% technical support staff	.0727***	(.00610)	.183***	(.0143)
Worker skill and training:				
College requirement for new officers	.0338***	(.0129)	.0686**	(.0348)
Hours of training for new officers	201***	(14.2)	560***	(42.4)
Include fixed effects and other controls?	Yes		Yes	
Instrument for computer index?	No		Yes	

NOTE.—This table reports regressions of measures of organizational structure on a computerization index. Each entry represents a coefficient estimate from a separate regression, where "Measure" is the left-hand-side variable and controls are included as specified in the bottom rows of the table. All regressions include year and agency fixed effects. The employees regression includes indicators for deciles of total offenses interacted with the log number of offenses as additional controls. The special units, organizational levels, directives, and percentage workers regressions include indicators for deciles of the number of employees interacted with the log number of employees as additional controls. The college requirement regressions include controls for the log number of agency employees as well as the per capita income and the percentage of residents 25 years and older with educational attainment of below high school, some high school, high school, some college, associate's degree, bachelor's degree, and advanced degree in each agency's geographic area. The training regressions include controls for the log number of agency employees and whether new entrants are required to have college experience. Column 2 instruments for the computer index using PC, mainframe, and minicomputer availability. The first-stage Wald statistics on these instruments are generally large. For college requirements, estimation using conditional logit yields similar results. Standard errors clustered on agency are reported in parentheses.
** Significant at the two-tailed 5% level.
*** Significant at the two-tailed 1% level.

crease in overall agency size, which suggests that the primary effect of IT on personnel is to enlarge the police department by adding employees who maintain the technology infrastructure as opposed to employees who perform more-traditional police functions.[24]

Although a number of papers have posited a link between increased demand for skilled labor and computerization (Mincer 1991; Bound and Johnson 1992), most past empirical studies of this proposition have relied on indirect evidence, such as cross-industry differentials in worker skill and computer use (Berman et al. 1994; Autor et al. 1998). Implicit in most models of computer-driven changes in skill premia is the notion that highly computerized firms would be more likely to hire better-educated workers because such workers can more productively use the available

[24] These results contrast with those of Doms et al. (1997), who find using panel data that increases in IT were not associated with increases in the nonproduction share of labor, and are instead more consistent with the findings of Berman et al. (1994).

IT. Past authors have also suggested that IT adoption can impose increased training requirements for new workers, leading to skill increases generated within the firm (Bresnahan et al. 2002).

The lower rows of table 7 demonstrate that a shift to complete computerization is associated with a 3.3% increase in the probability of requiring college education, a sizable increase given that only about 13% of agencies require college education. Instrumenting the index to account for measurement error yields an even larger estimate. Indeed, in 1997, agencies reporting PC use were twice as likely to report college requirements for entering workers than were those not reporting PC use. IT adoption is also associated with large increases in training.[25]

Overall, we see evidence that police departments that obtained IT during our sample period also implemented other organizational changes, becoming larger and more specialized and employing a more highly skilled workforce. This evidence is consistent with the possibility that IT is only one component of a larger system of reorganization that is required in order to improve the productivity of policing.

To further examine possible complementarities, in the first column of table 8 we present estimates of the relationship between IT use and crime, controlling for the organizational changes documented in table 7 along with computer use for reporting purposes. After other organizational changes coincident with the adoption of IT are accounted for, there is no longer evidence that IT itself is associated with changes in either case solution rates or offending rates.[26]

We next construct an indicator equal to one for agencies that simultaneously possess a high level of IT (more than half of the computer/data functions included in the computer index), high specialization (more than four special units), and highly skilled workers (more than 6 months of required training or college requirements), which we label "modern" agencies. The share of modern agencies defined in this fashion grew from 17% of agencies in 1987 to 44% of agencies by 2003.[27] We include this indicator as an additional explanatory variable and report its estimated coefficient

[25] Although the magnitudes of the estimated effect of IT use on training appear to be large, they are not unreasonable, given the enormous increase in training observed over the sample period. Between 1987 and 1990, the period that saw the largest rise in the adoption of IT, the average number of training hours rose from 163 to 633, an almost fourfold increase. By 2003, almost half of the sampled agencies required new officers to undergo more than 6 months of training.

[26] Unreported IV regressions designed to account for measurement error yield similar results.

[27] Among the agencies reporting information about IT, specialization, and the use of skilled workers, this growth primarily represents an expansion of the latter two modern practices. The share of these larger agencies with high levels of IT grew from 69% to 84% between 1987 and 2003, while the share reporting modern practices increased from 20% to 48% over the same period.

Table 8
Complementarities between Information Technology and Modern Organization

	Primary Explanatory Variable	
Productivity Outcome	Computer Index (1)	Modern Policing Indicator (2)
Crime clearance rate:		
All crime	−.00208 (.00757)	.00059 (.00641)
Violent crime	.00492 (.0139)	.00214 (.00942)
Property crime	.00066 (.00660)	.00288 (.00461)
Offense rate:		
All crime	.00085 (.00096)	−.00178** (.00090)
Violent crime	−.00094 (.00019)	−.00000 (.00033)
Property crime	.00095 (.00087)	−.00178** (.00077)
Include year and agency fixed effects?	Yes	Yes
Control for computerized reporting?	Yes	Yes
Control for organizational change?	Yes	Yes

Note.—This table reports regressions of productivity on information technology (IT), accounting for other types of organizational change. The regressions in col. 1 are identical to those presented in col. 2 of table 2 but include as additional controls indicators for the number of special units, functions, organizational levels, and written directives; the percentage of sworn employees, field operations personnel, and technical support personnel; the number of required training hours; an indicator for a college requirement; and an indicator for computerized record keeping. Missing observations for these additional controls have been set to their mean value, and dummy variables identifying missing values have been included in these regressions. See notes for table 2. The regressions in col. 2 include the same controls but also introduce an indicator variable for agencies with a modern structure, which is defined by simultaneous employment of high IT (IT index above 0.5), a specialized workforce (five or more special units), and a high-skill workforce (college requirement or more than 6 months of training); the estimated coefficients for this indicator are reported in the table.
** Significant at the two-tailed 5% level.

in column 2 of table 8. Because these regressions already control for the individual organizational and computerization measures underlying the modern agency indictor, the coefficient on this indicator provides an estimate of the added effect of jointly implementing IT, specialization, and a skilled workforce relative to enhancing only one or two of these dimensions. As in our previous specifications, we include a full set of police agency fixed effects in these regressions to account for unobserved agency-specific heterogeneity.

The coefficient estimates on the modern policing indicator are all positive for case solution rates, albeit not statistically significant. For offense rates, there is a negative and statistically significant relationship between the modern policing indicator and overall and property crime. The estimated coefficient implies that an agency implementing a combination of IT, specialization, and skilled workers experiences a roughly 5% lower offending rate than does an agency with similar levels of IT that has not implemented these other practices. The notion that IT is more effective when it is coupled with other organizational changes is consistent with the presence of complementarities.

Our panel results provide some evidence of complementarities between computerization and general organizational restructuring. In the law enforcement context, modern policing has been closely identified with a particular systems approach known as Compstat, which was first introduced by the NYPD in 1994 by Commissioner Bratton. In the popular imagination, Compstat is characterized by two elements: the real-time mapping of crime and the notorious early morning meetings where commanders must show that they understand and are reacting to the crime patterns projected on overhead screens. The program, in actuality, has additional elements. Weisburd et al. (2003) argue that Compstat is composed of the following six elements: (1) a statement of the measurable goals of the department; (2) internal accountability, particularly through Compstat meetings (managers are accountable for understanding crime patterns and reacting to them); (3) geographic organization of command (district commanders have the authority and resources to accomplish goals within areas); (4) empowerment of middle managers; (5) data-driven problem identification and assessment; and (6) innovative problem-solving tactics.[28]

Toward the end of the sample period, the LEMAS survey included questions about management practices that allow us to capture this more specific description of complementarities. We identify four management techniques corresponding to elements identified by Weisburd et al. (2003): (1) the use of IT for crime data collection and analysis (element 5 above), (2) a problem-solving paradigm (element 6 above), (3) the use of feedback for priority setting and evaluation (relating to elements 1, 2, and 5 above), and (4) a geographic-based deployment structure (element 3 above). Following the economics literature on skill complementarities, we include a fifth management practice—the use of more highly educated officers.

Ideally, to test the complementary explanation, we might use regressions similar to those in Section III with separate and interacted measures of IT and management practices as explanatory variables. Unfortunately, this approach is limited by our available data in two important ways. Most of the questions regarding management practices identified by Weisburd et al. (2003) as key to improving police performance were not asked in the LEMAS survey prior to 1997, by which time many larger agencies had already implemented Compstat or similar programs. The other major data limitation is that because of the subjective nature of some of the questions regarding management practices, there appears to be some inconsistency across years in reported practices, potentially rendering inferences based on within-agency time-series variation in practices mis-

[28] Other accounts coincide with the broad elements, although not with all the details. For example, the *New York Times* summarizes the program as consisting of "specialized units, statistics-driven deployment, and a startling degree of hands-on leadership" (Dewan 2004).

leading.[29] To overcome these limitations, we average responses to individual survey questions across years to develop an agency-level indicator for each of the aforementioned management practices covering the period 1997–2003. We then define Compstat agencies as those that simultaneously had elements of all five key management techniques in at least half of the sample years.[30] Our regressions examining complementarities thus exploit cross-sectional variation in IT and management practices.[31]

Columns 2 and 3 of table 9 report coefficient estimates from regressions of the average agency clearance rate during 1997–2003 on agency-level indicators for Compstat use and on separate indicators for each of the five components that a Compstat system comprises. Separate specifications are reported for total, violent, and property crimes, and all regressions include demographic controls. The bottom row of the table reports the overall effect for an agency implementing Compstat, which is obtained by summing the estimated coefficient on the Compstat indicator and the coefficients for each of the constituent elements. The results are striking. Whereas the estimates on each of the individual management practices are of negligible magnitude and are generally statistically indistinguishable from zero, the combination of practices into a Compstat system yields positive and significant effects on overall and violent clearance rates. The overall effect estimate for total crime of around 3 percentage points implies a roughly 15% gain relative to the average clearance rate of 22%. For violent crimes, which in many cases are an area of particular investigative emphasis, the point estimates are even larger, albeit less precisely estimated.[32]

Columns 4–6 report comparable regressions with offense rates as the

[29] For example, one survey item asks whether officers use a particular police problem-solving methodology known as SARA (scanning, analysis, response, and assessment). The Little Rock Police Department reported using SARA in 1997, 1999, and 2003 but not in 2000, while the Bakersfield Police Department reported using SARA in 2000 but not in 1997, 1999, or 2003. The police department in Hillsborough, CA, reported using SARA in 1997 and 2000 but not in 1999 and 2003.

[30] The construction of these variables is described in greater detail in the appendix.

[31] In unreported cross-sectional regressions of overall clearance and offense rates on the average computer index and demographic controls for the same set of agencies and years, we replicate our finding from the panel analysis that more IT is not associated with improvements in clearance rates but is associated with increases in offending rates.

[32] Given our findings here, one natural question is whether the outcome regressions reported previously suffer from omitted variable bias due to failure to control for management practices. If the management practices are positively correlated with computer use (as they are in our sample) and are actually beneficial in solving cases or deterring crimes, the omission would bias our estimates toward finding an effect, which we do not.

Table 9
Complementarities between Information Technology and Management Practices in Solving and Deterring Crime

Explanatory Indicator	Clearance Rate: All Crime (1)		Clearance Rate: Violent (2)		Clearance Rate: Property (3)		Offending Rate: All Crime (4)		Offending Rate: Violent (5)		Offending Rate: Property (6)	
Compstat	.0182**	(.00830)	.0284**	(.0132)	.0113	(.00799)	−.00624***	(.00211)	−.00048	(.00029)	−.00576***	(.00191)
Computer use	.00220	(.00948)	.0127	(.0159)	.00425	(.00938)	.00394	(.00205)	.00025	(.00031)	.00369**	(.00184)
Highly skilled workers	.00702	(.00573)	−.00090	(.00966)	.0121**	(.00566)	.00634***	(.00150)	.00055***	(.00020)	.00579***	(.00136)
Problem-solving emphasis	−.00394	(.00580)	−.0183	(.0100)	−.00188	(.00570)	.00829***	(.00167)	.00068***	(.00021)	.00761***	(.00151)
Geographic awareness	.00762	(.00636)	.00959	(.0104)	.00676	(.00634)	.00151	(.00146)	.00011	(.00020)	.00140	(.00132)
Evaluation	.00098	(.00571)	.00178	(.0100)	.00282	(.00562)	.00380**	(.00152)	.00021	(.00020)	.00359***	(.00138)
Overall effect	.0321***	(.0121)	.0333	(.0208)	.0354***	(.0120)	.0176***	(.00300)	.00131***	(.00042)	.0163***	(.00271)
N	1,768		1,765		1,768		1,768		1,768		1,768	
R^2	.224		.291		.215		.332		.510		.297	

Note.—This table reports agency-level regressions of the 1997–2003 average clearance rate (arrests/offenses; cols. 1–3) and offending rate (offenses/population; cols. 4–6) on indicators for a Compstat system as well as individual modern police management practices. Each column entry reports coefficient estimates from a separate regression. Agencies with a Compstat system simultaneously implemented elements of all five of the listed management practices in more than half of the sample years between 1997 and 2003. All regressions control for the average percentage black, percentage Hispanic, per capita income, and poverty rate of the area covered by the agency, average log number of agency employees, the average number of years in which the agency reported computer use for record keeping, and state fixed effects. Heteroskedasticity-robust standard errors are reported in parentheses.

** Significant at the two-tailed 5% level.

*** Significant at the two-tailed 1% level.

dependent variable. Whereas several of the individual management practices appear to be positively associated with offense rates, the Compstat system indicator is negatively and significantly related to total and property offending. Relative to agencies with otherwise similar sets of management practices but without the full Compstat system, those agencies implementing Compstat experienced lower crime rates. The magnitude of this coefficient is small to moderate, implying, for example, that using Compstat has an effect on crime rates equivalent to the effect that a 5.5-percentage-point increase in the poverty rate would have. However, it should be noted that the aggregate effects of a Compstat system on offending are positive and significant, indicating that, on net, Compstat agencies had higher crime rates than did agencies without any of the constituent elements. One explanation for this finding may relate to reporting practices that are not fully captured by controlling for computerized record keeping. For example, problem-focused policing may include aggressive enforcement of quality-of-life crimes and community outreach efforts, both of which might increase recorded crime.

Given that we have only approximate measures of the Compstat practices and are forced by data limitations to rely on cross-sectional variation, our results on the role of specific complementarities are only suggestive. In particular, because we cannot directly measure Compstat, it remains possible that the combined set of practices we measure captures some unobserved factor that influences productivity rather than complementarities. For example, agencies that adopt IT and modern practices may have better managers, and superior managers may explain some of the crime decreases and clearance rate increases that we observe in modern police agencies. Taken together, however, the results in tables 7–9 support the hypothesis that an additional reason for the weak aggregate relationship between general IT and policing outcomes may be that while many agencies use some type of IT, relatively few have implemented all of the complementary organizational and management practices that allow IT to influence police effectiveness.[33]

V. Conclusions

This article provides new microlevel evidence on the manner in which IT influences productivity in the public sector. We demonstrate that increases in IT in police departments are not strongly associated with improved case solution rates, clearance rates, or conviction rates, and com-

[33] One natural question arising from these findings is why Compstat or similar programs are not more widely used by police agencies. Possible factors limiting Compstat adoption include the high monetary cost of implementing all the necessary practices, police union resistance to higher accountability standards, and diffusion lags in knowledge of Compstat management techniques.

puting technology that increases recorded crime actually generates the appearance of lower productivity. However, while there is no statistically significant relationship between general IT and crime fighting and deterrence (in spite of our large samples), productivity improvements become relatively large when IT adoption is undertaken as part of a whole package of organizational changes. These results endorse the complementarity hypothesis. Police agencies, like firms, appear likely to enjoy the benefits of computerization only when they identify the specific ways in which new information and data availability interact with existing organizational practices and make adjustments accordingly. Our findings regarding complementarities may help explain the increased complexity, specialization, and demand for skilled labor that have occurred in many portions of the public sector over the last quarter century.

Our findings have two important implications for future research on the impact (or lack thereof) of IT on productivity. First, if the primary effect of IT comes through its combination with other types of organizational innovation, studies that consider IT in isolation may miss an important piece of the productivity picture. For example, our study suggests that IT introduced in conjunction with changes in job design, accountability, or training may improve outcomes in health care or educational settings, despite contrary evidence from existing studies that consider IT independently (e.g., Garg et al. 2005; Goolsbee and Guryan 2006).

Second, although many researchers treat IT as a somewhat generic input into production, our findings regarding the differential impacts of recordkeeping systems and other types of computing technology suggest the need to more carefully consider the specific features of information technologies.[34] More generally, computers may themselves alter the quality and type of data available to researchers in ways that obscure productivity computation. Distinguishing the different channels through which IT might influence not only performance but also its measurement remains an important area for future research.

Appendix

Construction of Management Practices Measures

To examine the role of complementarities in crime reduction, we require separate agency-level measures of computerization along with relevant modern police management practices. Following Weisburd et al. (2003), we identify five components of a Compstat system: (1) information technology for crime data collection and analysis, (2) the use of skilled officers,

[34] As we argued in this article's introduction, Hubbard (2003) and Athey and Stern (2002) are examples of exceptions.

(3) a problem-solving paradigm, (4) feedback-based evaluation, and (5) a geographic-based deployment structure. We code individual survey items as either 0 or 1 (no or yes) to construct each of the five practice measures. The constituent survey questions corresponding to each practice measure are as follows.

1. Information technology (3)
   - Does the department use computers for crime analysis?
   - Does the department use computers for crime mapping?
   - Does the department use computers for investigation?
   - Does the department maintain computerized data on criminal histories?
   - Does the department maintain computerized data on crime incidents?
   - Does the department maintain computerized data on stolen property?
2. Skilled officers (1)
   - Are more than 6 months (1,040 hours) of training provided for new officers?
   - Are new officers required to have previous college experience?
3. Problem solving (1.5)
   - Are officers encouraged to use SARA-type problem solving?
   - Are collaborative problem-solving criteria used in officer evaluations?
   - Does the agency engage in problem-solving projects with community groups or government agencies?
4. Feedback-based evaluation (1)
   - Is citizen survey information collected and provided to patrol officers?
   - Is citizen survey information collected and used for allocating resources?
   - Is citizen survey information collected and used for prioritizing crime/disorder problems?
   - Is citizen survey information collected and used for redistricting patrol areas?
5. Geographic deployment (1)
   - Are officers assigned to geographic areas?
   - Are detectives assigned cases on the basis of geographic areas?

The numbers in parentheses above correspond to the average number of annual survey questions that must be answered positively in order for an agency to be classified as employing a particular management practice. For example, an agency that answered yes to two of the problem-solving questions in 1997 and 1999, one in 2000, and three in 2003 would have an average problem-solving response of 2 (which is greater than the criterion of 1.5), so its problem-solving practice indicator would be coded as 1. We consider a department as having a Compstat system in a given year if it answered yes to at least one of the constituent survey items for each of the five practices in a given year. Compstat agencies were agencies that used Compstat systems in at least half of the available survey years. Of the 1,768 agencies in our pooled sample, 11.4% used Compstat, 85.6% used information technology for crime analysis, 39.9% used highly skilled officers, 38.5% used problem-solving practices, 63.6% used geographic deployment, and 41.3% used feedback-based evaluation.

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