DOES VOTING TECHNOLOGY AFFECT ELECTION OUTCOMES? TOUCH-SCREEN VOTING AND THE 2004 PRESIDENTIAL ELECTION

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Abstract—Critics argue that electronic voting is vulnerable to fraud. We test whether voting technology affected electoral outcomes in the 2000 and 2004 presidential elections. We find a positive correlation between use of electronic voting and George Bush vote share. The effect could have been large enough to influence the final results in some swing states. While this pattern would appear to be consistent with allegations of voting irregularities, a closer examination suggests this interpretation is unlikely. We find no evidence that electronic voting had a larger effect in swing states, or in states with a Republican secretary of state. We also find that electronic voting has a negative effect on turnout rates of Hispanics (who tend to favor Democrats). Electronic voting was more likely to be used in counties with a higher fraction of Hispanics; especially in swing states.

I. Introduction

THE difficulty of counting the ballots in Florida during the 2000 presidential election drew the nation's attention to the issue of voting technology. Backed by funding from a new federal law—the Help America Vote Act of 2002—many counties across the United States have responded by installing touch-screen voting machines.[1] Supporters of this new technology (also known as "direct recording electronic" voting) point to several advantages, including accessibility for disabled and non-English-speaking voters, the instant availability of vote counts, and ease of implementing last-minute ballot changes.[2]

Nevertheless, before, during, and after the most recent presidential election concerns were raised that touch-screen voting systems may be vulnerable to fraud.[3] Distrust in electronic voting is not limited to "conspiracy theory" Web sites. It is shared by the mainstream press and some members of Congress, and is substantiated by peer-reviewed academic studies. A technical analysis of the software used in one company's electronic voting equipment showed the potential vulnerability of the system to manipulation (Kohno et al., 2004). Critics' concerns increased when, just prior to the 2004 election, the CEO of that company told Republicans that he was "committed to helping Ohio deliver its electoral votes to the president."[4] The day after the election some of these concerns seemed validated by the discovery of an error in electronic voting machinery that gave President Bush more votes than had actually been cast in one Ohio precinct.[5] Reports of voting irregularities prompted a formal objection to the Ohio election results by a number of Democratic congressmen.[6]

Although not all the controversies surrounding recent election results are related to voting technology, concerns over touch-screen voting seem to have generated the most widespread debate. A *New York Times* editorial summarized the state of public skepticism on this new voting technology, concluding that "these ATM-style machines make a lot of sense for the manufacturers because they are expensive. But touch-screen machines are highly vulnerable to being hacked or maliciously programmed to change votes."[7] Distrust in the reliability of electronic voting machines has led to dozens of lawsuits around the country challenging the process of certification of voting technologies. As a result of these suits and associated legislative delays, a majority of the states failed to meet the January 1, 2006, target under the Help America Vote Act for implementation of new voting technologies (NASS, 2005).

One of the reasons why the choice of voting technology is so controversial is that there is little systematic empirical evidence on the relationship between voting technology and election outcomes.[8] In this paper we use county-level data from the 2000 and 2004 presidential elections to test

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[1] HAVA provides funding for adopting one of two electronic voting systems: optical scan systems, which rely on a paper ballot marked with a pencil, and touch-screen systems. See Katz and Bolin (2005).

[2] See, for example, the customer comments on the Patriot voting system sold by Unilect Corporation at http://www.unilect.com.

[3] Reflecting these concerns, California's secretary of state published guidelines in December 2003 that required all touch-screen voting systems purchased by cities or counties after July 2005 to include an "accessible voter verified paper audit trail." GAO (2005, pp. 22–31) presents a succinct summary of concerns regarding electronic voting machines.

[4] The August 14, 2004, letter from Walden O'Dell of Diebold—who was active in the reelection effort of President Bush—prompted Democrats to question the propriety of allowing O'Dell's company to calculate votes in the 2004 presidential election.

[5] The error occurred in a precinct in Columbus, Ohio. The original electronic tally showed Bush receiving 4,258 votes to Democrat John Kerry's 260 votes. However, only 638 voters cast ballots in that precinct. The error was later corrected by election officials.

[6] The objection was supported by only one Senator, Barbara Boxer (D-CA). (*San Francisco Chronicle,* January 7, 2005). Problems with electronic voting systems have continued after the presidential election. A *New York Times* article (April 1, 2005) noted that "a computer glitch caused Miami-Dade electronic voting machines to throw out hundreds of ballots in a special election on March 8, 2005, and raised questions about votes in five other municipal elections. The problem came to light when officials noticed a large number of undervotes in the election."

[7] *New York Times,* March 10, 2005.

[8] The only paper that we are aware of that directly studies the effect of technology on election outcomes is Hout et al. (2004). They argue that electronic voting increased the number of votes for Bush in Florida by 130,000 to 260,000 votes. McDonald (undated) presents a critique of this study. Brady et al. (2001), a group at CalTech-MIT (Alvarez et al., 2001) and Dee (2005) focus on the related question of which voting technology generates the lowest fraction of spoiled or residual votes (ballots that cannot be counted for any particular candidate).

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whether voting technology affects electoral outcomes. Clearly, due to its illicit nature, it is difficult to find direct evidence of vote tampering. Instead, following the approach of other recent studies that have tried to detect illegal behavior, we use publicly available data on voting outcomes across counties to test for patterns that could be suggestive of manipulation.[9] In particular, we focus on interactions between the use of touch-screen machinery and the incentives faced by local officials to tip the vote in one direction or the other.

We begin by comparing the change in the Republican two-party vote share between 2000 and 2004 in counties that adopted touch-screen voting technology and counties that did not. The results suggest that the gain in the share of votes cast for George Bush between 2000 and 2004 was greater in counties with touch-screen voting. The gap is fairly large, accounting for 1.4 percentage points of the 2000–2004 gain in the Republican two-party vote share—enough to have affected the final outcome of the election.

Of course these results do not necessarily prove that voting technology matters. An alternative explanation is touch-screen voting was more likely to be adopted in counties where support for Republican presidential candidates was accelerating. We therefore focus on models for the change in the Republican vote share that control for a wide variety of observed election determinants, including state fixed effects, controls for the Republican and third-party vote shares in the county since 1992, income, church membership, presence of military personnel, and racial composition. In these models the difference in the change in the 2000–2004 Republican two-party vote share between counties with and without touch-screen voting falls to 0.2–0.3 percentage points, but remains marginally significant. Although small, this effect would have been large enough to influence the final result in some closely contested states, and therefore the final election outcome.

Is the gap in Republican vote share between counties with and without touch-screen voting evidence of systematic irregularities on the part of Republican election officials, or just a spurious correlation? To provide further insights we turn to tests based on the notion that incentives for vote manipulation vary widely across counties. If irregularities did take place, they would be most likely in counties that could potentially affect statewide election totals, or in counties where election officials had incentives to affect the results. For example, there are few incentives for vote tampering in solidly Democratic or solidly Republican states like California or Texas, since small changes in a county's vote tally have no effect on the final outcome. On the other hand, incentives are higher in states like Ohio or Florida, where minor changes in counts from a small number of counties could affect the outcomes under the "winner-take-all" electoral college system. Similarly, in the presence of irregularities associated with voting technology, one might not expect touch-screen voting to favor Republicans in states where election officials are Democrats.

In this spirit, we estimate models that include interactions between an indicator for touch-screen voting and indicators for whether the state was a swing state and whether the secretary of state (or the governor) was Republican. We find no evidence that these interaction effects are positive. Indeed, if anything, the touch-screen voting effect is smaller in swing states, and in states with a Republican secretary of state. These results are inconsistent with the irregularity hypothesis.

As a further check, we estimate a parallel set of models for the change in the share of voters registered as Republicans. Trends in registration presumably reflect trends in voter sentiment but should not be affected by voting technology. Thus any relation between touch-screen voting and the change in the Republican share of registered voters suggests a problem with unobserved heterogeneity that could also bias the relation between touch-screen voting and vote shares.[10] Results from this investigation suggest that changes in the relative shares of registered voters are unrelated to use of touch-screen voting, although the power of the exercise is limited by the lack of complete data on county-level voter registration.

If the touch-screen voting effect cannot be explained by voting irregularities, or by omitted variables, why is there a relationship between touch-screen voting and changes in support for Bush? One possible link is through voter turnout: if touch-screen voting affects the relative turnout of groups with systematically different voter preferences, it could affect vote share outcomes. We find that touch-screen voting is associated with lower turnout rates, and that this effect is larger in counties with a larger fraction of Hispanics. Since Hispanics tend to vote for Democrats, this turnout effect may ultimately affect the election outcomes. On the other hand, there is no similar interaction with the fraction of black residents in a county.

Finally, we present models where technology adoption is the dependent variable. Controlling for state effects, these models suggest that touch-screen voting was more likely to be adopted in counties with higher fractions of black and Hispanic voters. Consistent with a possible partisan motive, the Hispanic effect is generally stronger in swing states, though not in states with a Republican governor.

Overall, we reach two main conclusions. First, although there is some evidence that use of touch-screen voting is correlated with the change in the Republican vote share in a county, caution is needed in interpreting these patterns. While the evidence appears superficially consistent with

[9] Recent examples include Duggan and Levitt (2002), Fisman and Wei (2004), Jacob and Levitt (2003), Hsieh and Moretti (2005), Di Tella and Schargrodsky (2003), Fisman (2001), and Reinikka and Svensson (2004).

[10] A similar test could be performed with exit poll data. However, county-level exit poll data are unavailable.

voting manipulation, more direct tests for systematic irregularities give no indication that the Republican gains are correlated with local incentives to raise the Republican vote share. We stress that our empirical strategy is intended to test for systematic voting irregularities, and cannot detect voting irregularities in only in one or two counties.

Second, touch-screen voting can affect election outcomes indirectly by affecting the relative turnout of different voter groups. The evidence suggests that touch-screen voting reduces overall turnout, with a larger effect in counties with more Hispanic residents. The fact that touch-screen voting seems to have been adopted more quickly in counties with more Hispanics (particularly in swing states) may point to systematic effort to influence election outcomes, though regardless of intention the overall effect on election outcome was small.

II. The Controversy Surrounding Voting Technology

A. *Voting Technologies*

The choice of voting mechanisms has long been a controversial issue, marked by periodic introduction of promising new technologies, ensuing debate, and persistent disparities in adoption choices around the country. During the 1880s and 1890s the practice of voting with preprinted ballots distributed by the political parties was gradually supplanted by the use of so-called Australian ballots, which list the full slate of candidates for both parties on a government-provided form.[11] Paper ballots based on this design were in widespread use by the mid-twentieth century, but are now used by only a small fraction of precincts (Alvarez et al., 2001). The first successful voting machines—lever-operated machines similar to those still in use today—were introduced in upstate New York in the 1890s (Harris, 1934). In principle these machines eliminated any ambiguity over the validity of a particular ballot, and also automated the counting of ballots. Because of their complex design, however, lever machines are expensive to buy and maintain. They also lack an independent audit trail of the votes cast. Punch card voting systems were developed in the early 1960s to take advantage of existing computer technology, offering an automated vote-counting system with the benefit of a paper audit trail.[12] The first punch card system—the Votematic system—was designed to use IBM card-processing equipment, and was soon purchased by IBM, only to be sold a few years later amid concerns over the reliability of the system (Nathan, 1980). An alternative system developed at about the same time used optical card readers to count ballots "bubbled-in" with a lead pencil. Optical scan systems are now the most widely used voter technology, and the only legacy technology certified under the Help America Vote Act.

The most recent innovation in voting technology is direct recording electronic (DRE) voting, in which voters' preferences are entered on a terminal device (such as a touch screen). A key advantage of DRE technology is its adaptability for disabled and non-English-speaking voters.[13] Like lever machines, DRE voting machines eliminate ambiguity in the determination of valid ballots and provide cumulative vote tallies without the need for mechanical card readers. The main criticism of DRE technology—echoed in the numerous lawsuits now facing state election boards around the country[14]—is that there is no direct way to verify the counting process or the final vote tally. These criticisms are addressed by the design of some DRE machines, which issue a paper record of the vote at the time of balloting.[15]

A second area of concern is that electronic voting may lead to a pattern of voting errors that is systematically biased in favor of one party or the other. The study by Alvarez et al. (2001) of voting in the 1988–2000 Presidential elections concluded that DRE voting has a surprising high rate of "residual" votes (votes that indicate no preference for a candidate)—higher than paper, lever, or optical scan voting, and comparable to the much-vilified punch-card voting systems. If these residual votes reflect errors that are more likely to be made by certain demographic groups, then adoption of DRE voting can lead to a bias in recorded votes relative to intended votes (Tomz & Van Houweling, 2003). A related concern is that the adoption of electronic voting machines can have a differential effect on voter turnout rates of different groups, leading to a "selectivity bias" in the set of voters relative to the underlying eligible population. This could happen if, for example, electronic voting machines are perceived as confusing or intimidating by minorities that have limited familiarity with computers

[11] See Harris (1934, pp. 17–20) and Jones (2003) for illustrations of the earlier party ticket ballots and a typical Australian ballot. As noted by Harris, the use of party tickets made it very easy to implement vote-buying schemes.

[12] The first punch card system—the Votematic system—was conceived by Joseph Harris (author of the authoritative 1934 report on election administration) and codeveloped with a Berkeley colleague; see Nathan (1980). This system, and the slightly different Data Punch system, are both still in use today.

[13] Indeed, several current lawsuits over the selection of voting technology have been filed by advocates for disabled voters who prefer DRE to optical scan voting, for example, *National Federation of the Blind v. Volusia County* (filed in U.S. District Court for the Middle District of Florida).

[14] Recent lawsuits in various states include *Diebold v. North Carolina Board of Elections* (North Carolina) challenging the process of technology certification in that state; *ACLU v. Connor* (Texas) challenging the decision process of the Texas election examiners; *Guscoria et al. v. McGreevey* (New Jersey) challenging the legality of the state's electronic voting machines; *Schade v. Maryland State Board of Elections* (Maryland) challenging the certification of voting machines made by the Diebold company.

[15] There are several versions of a paper record auditing system. One system requires that the DRE machine create a completed paper ballot that the voter must approve, and which subsequently becomes the "ballot of record" (Mercuri, 2002). This system essentially uses the electronic terminal as a vote casting system and an optical card reader for ballot counting.

and ATM machines, or if the introduction of a new technology leads to longer lines at polling stations in certain areas.

B. *The Adoption Process*

The choice of voting technology for federal elections is governed by state law. A handful of states (Delaware, Georgia, Hawaii, Maryland, Nevada, North Dakota, and Oklahoma) prescribe a single voting technology for all precincts in the state (EDS, 2006). In other states, however, a state election board (or a specially constituted technology board) approves particular voting technologies, and lower-level jurisdictions (typically, counties) select from the approved set of methods.[16] Local election authorities typically buy and own voting machinery, and have to pay for any new equipment, though many states provide grants to offset the costs of new technology. As was noted by Harris (1934) in his analysis of technology adoption in the early twentieth century, there are two problematic features of the technology selection process. First, state laws contain many conflicting and arguably obsolete requirements.[17] Second, and most importantly, the officials in charge of approving alternative technologies, and of selecting from among the approved choices, are typically either elected or appointed on a partisan basis, and have a direct interest in the election outcomes.

With these facts in mind, several characteristics of the technology adoption process stand out. First, as emphasized by Knack and Kropf (2002) and Herron and Wand (2004), the choice of voting technologies by different local authorities is clearly nonrandom. In the case of DRE adoption, some of this heterogeneity may be related to the relative wealth of local districts, since the machinery is expensive ($3,000 or more per machine) and tends to have relatively high maintenance and operating costs. Second, technology choices tend to be persistent over time, reflecting the relatively long life of the machines (especially lever and punch card systems), and the adjustment costs of switching to a new technology. This persistence may contribute to the fact that DRE adoption has been slower in many larger Northern cities, where lever and punch card voting systems were adopted decades ago. A final observation is that voting machinery tends to be "customized" for the buyer, driven in part by the necessity of complying with state regulations. As a result, the actual operation of a given technology may vary from precinct to precinct. An interesting example is the case of Cook County, Illinois, which operated a punch card voting system in the 2000 election that included automatic checking features for over- and undervoting that were "turned off" because state laws did not allow ballot-screening features (Wilson, 2006).

[16] In reality, local authorities often choose "unapproved" machinery in anticipation that the machines will be approved at the state level.

[17] For example, New York law has a requirement that the "entire ballot be visible at once" (Madore, 2006), seemingly necessitating the use of physical ballots. Some states (such as North Carolina) have recently passed laws that require manufacturers of electronic voting machines to submit all of the computer code for their machines (Zetter, 2005). Many state laws also conflict with the requirements of the federal Help America Vote Act.

III. Voting Technology and Presidential Election Outcomes

In this section we analyze the relationship between voting technology and presidential voting outcomes. After a brief discussion of our data sources, we present estimates from an initial set of models that relate the 2000–2004 change in the two-party Republican vote share to an indicator for touch-screen voting technology and a rich set of covariates. We then present models in which the presence of touch-screen voting is interacted with a number of state or county characteristics that might be expected to be associated with irregularities. Finally, we present models where the dependent variable is the Republican share of registered voters.

A. *Preliminary Evidence*

We begin by showing how voting technology has changed across counties between the 2000 and the 2004 presidential election. Our use of counties as a unit of analysis is dictated by the fact that in most states, voting technology is selected by officials at the county level, and is homogeneous within counties.[18] Data on voting technology for the 2004 election were obtained from ElectionOnLine.com. We validated these data for all swing states and several other states using information collected directly from the secretaries of state. We also compared the data with information provided by Election Data Services. We found relatively few discrepancies between the three data sources. Similar data for the 2000 presidential election were purchased from Touch-screen Voting Technology, and corrected using information generously provided by Stephen Ansolabehere.[19] County data on religious adherents are from Jones et al. (2002). The remaining data on county characteristics are from the 2000 Census of Population.

Table 1 shows the prevalence of different voting technologies in the two most recent federal elections. All means are weighted by county population. Just over 27% of U.S. counties used DRE technology in the 2004 election, up from 13% in 2000. Although we do not report the results, the

[18] In eight states—Connecticut, Maine, Massachusetts, Michigan, New Hampshire, New York, Vermont, and Wisconsin—choice of technology is made at a lower level, typically at the township level. Of the 281 counties in these states, 166 had the same voting technology throughout the county in 2004. Thus, there are only 115 counties with multiple technologies. We were able to obtain subcounty data on technology choices for five of these counties and use the fraction of townships with DRE technology (instead of an indicator of DRE choice) as a measure in these counties.

[19] There is some controversy over the reliability of the 2000 technology data—see Brady et al. (2001). Unfortunately, we were unable to obtain corrections made by Brady et al.

TABLE 1.—VOTING TECHNOLOGY USE IN 2000 AND 2004 ELECTIONS

	Weighted Means Across Counties:	
	2000	2004
Direct electronic (DRE)	12.9	27.2
Paper ballot	3.2	1.8
Lever	13.7	12.4
Punch card	30.9	11.8
Optical scan	34.9	41.8
Unknown	4.2	4.9

Note: Overall sample includes 3,053 counties in fifty states (Alaska is not included) with data on voting technology in 2000 and 2004. Sample means are weighted by county population in 2000. See text for sources.

unweighted use rates of DRE technology are lower (20% in 2004), indicating that larger counties are more likely to adopt DRE technology.[20] Southern counties are disproportionately represented among DRE adopters, accounting for 78% of counties using DRE in the 2004 election versus 38% of counties using other technologies.

The other rows in table 1 show the prevalence of other voting technologies, including optical scanning technology (used by the 42% of counties in 2004), paper ballots (under 2% of counties), lever voting machines (12% of counties) and punch cards (12% of counties). Note that the rise in the share of counties using DRE technology is mainly accounted for by the sharp decline in the fraction using punch cards. Optical scanning technology also gained share, while lever and paper technologies were more stable.

How was the adoption of DRE technology related to trends in election results? Across all counties in the United States, the gain in the Republican share of the two-party vote between 2000 and 2004 was larger in counties that used touch-screen voting in 2004 than in other counties. The gain was 3.2 percentage points (standard error = 0.2) in DRE counties versus 1.8 percentage points (standard error = 0.07) in non-DRE counties. This implies a "DRE effect" equal to 1.4 percentage points, large enough to affect the final outcome of the election. The difference in the distribution of the change in vote shares between DRE and non-DRE counties is illustrated in figure 1. The "Dre" line is the kernel density plot for the change in the Republican vote share in counties that used touch-screen technology in 2004. The "No Dre" line is the kernel density plot for counties that did not use touch-screen technology in 2004. While there is significant variation within each group, the distribution in the DRE counties is clearly shifted to the right.

Of course, the interpretation of this finding is not clear-cut. On one hand, it is consistent with concerns raised by some Democrats that the adoption of touch-screen voting helps Republicans. This interpretation is particularly troublesome because the magnitude of the estimated coefficient is large enough to have influenced the final result in several swing states, potentially altering the final outcome of the election. On the other hand, it is possible that the adoption of touch-screen voting is correlated with other determinants of electoral outcomes that coincidentally raised the Republican vote share faster than in nonadopting counties.

B. *Econometric Specifications*

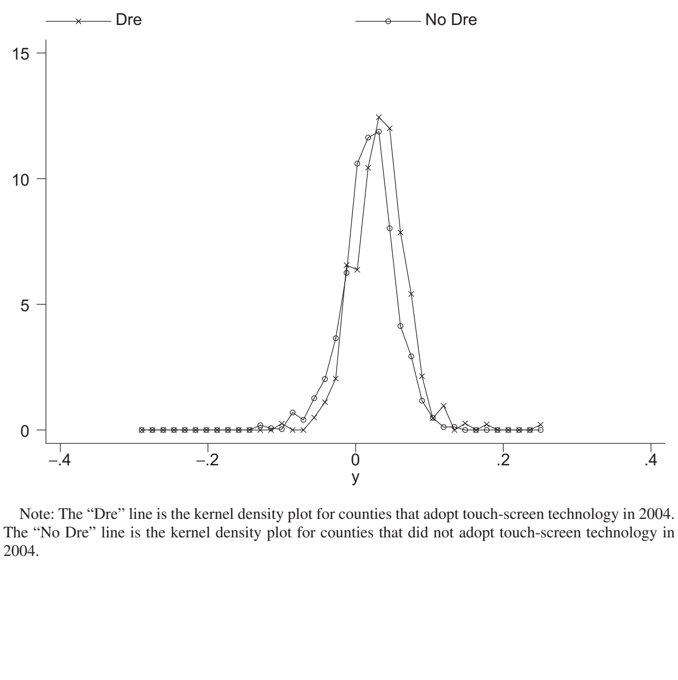
To try to shed more light on this issue, we turn to a more formal econometric analysis. We begin by estimating variants of the following model:

$$\Delta V_{cs} = \beta_1 DRE_{cs2004} + \beta_2 DRE_{cs2000} + \beta_3 V_{cs2000} + \beta_4 V_{cs1996} + \beta_5 V_{cs1992} + \beta_6 T_{cs2000} + \beta_7 T_{cs1996} + \beta_8 T_{cs1992} + \beta_9 X_{cs} + d_s + e_{cs}, \quad (1)$$

where ΔV_{cs} is the 2000–2004 change in the Republican two-party vote share in county c in state s; DRE_{cs2004} and DRE_{cs2000} are indicators for whether county c used touch-screen voting in 2004 or 2000, respectively; V_{cst} is the two-party vote share in county c in year t (t = 2000, 1996, or 1992); T_{cst} is the third-party vote share in county c in year t; X_{cs} is a vector of county characteristics that might affect electoral outcomes (including percent in the military, percent who are religion adherents, percent blacks, percent Hispanics, median income, percent college graduates, percent in agriculture, and county population), and d_s is a vector of state dummies.

By focusing on the change in the Republican vote share, we are eliminating any permanent differences across counties in voter sentiment. By controlling for state effects, we absorb any unobserved state-specific shocks that might have

FIGURE 1.—DISTRIBUTION OF 2000–2004 CHANGES IN BUSH VOTE SHARE BY VOTING TECHNOLOGY



Note: The "Dre" line is the kernel density plot for counties that adopt touch-screen technology in 2004. The "No Dre" line is the kernel density plot for counties that did not adopt touch-screen technology in 2004.

[20] Counties with DRE voting had an average population of about 119,000 in 2000 compared to an average population of 82,000 in non-DRE counties.

affected the 2000–2004 change in vote shares in that state. Identification of the DRE effect in model (1) comes from the fact that in many states there is county-level variation in voting technology. Specifically, identification comes from variation across counties in the subset of 23 states that have both DRE and non-DRE voting technologies.[21] By including lagged Republican and third-party vote shares, we control for preexisting county-specific trends in voter sentiment that might be correlated with use of touch-screen voting. Finally, by adding the covariates we hope to account for county-specific economic and cultural factors that could affect the rate of change in voter sentiment and might also be correlated with technology adoption. We have also fit all of our models using as a dependent variable the change in the Republican vote share (rather than the Republican share of the two-party vote) and found results that are quite similar to the ones that we report here.

An implicit assumption in model (1) is that the only voting technology that matters is touch-screen voting. The other possible technology choices are combined together as the omitted reference group. Given the controversy over touch-screen voting we believe this specification is reasonable. It also simplifies the interpretation of our results, since otherwise one has to specify which of the voting technologies is used as the baseline for comparing the enumerated choices. Our models identify the effect of touch-screen voting relative to an average of the other technologies. However, for completeness we also present models that include every possible combination of voting technology in 2000 and 2004.

Note that in model (1) we do not impose the assumption that touch-screen voting had the same effect in both 2000 and 2004 (in other words, that $\beta_2 = -\beta_1$). When we present estimates of equation (1), however, we test for this restriction, and find it is generally consistent with the data.

A final specification issue is that equation (1) implicitly restricts the effect of touch-screen voting to be the same across all counties. For a number of reasons this may be an inappropriate restriction. In particular, if one is concerned about voting irregularities associated with the adoption of DRE, it is implausible that these irregularities occurred in every county. If there were such manipulations, we would expect to see them only where they could have made a difference for the overall election outcome, or in states where elections officials had an incentive and the opportunity to favor one candidate.

[21] A total of four states used only touch-screen voting in 2004 (Delaware, Georgia, Maryland, and Nevada). Another twenty states and the District of Columbia had no counties with DRE voting. Two states (New York and Wisconsin) with township-level choice of voting technology had some counties with partial use of DRE, but no counties with full DRE adoption. In these two states, we coded a county as having adopted DRE if at least half of its population resided in townships that adopted DRE. We have no data on Alaska.

To test this possibility, we estimate models that include interactions of the change in the use of DRE with state or county characteristics that one would expect to be associated with an increase the chances of frauds in favor of Republicans:

$$\begin{aligned}\Delta V_{cs} &= \beta_1 \Delta DRE_{cs} + \beta_2 \Delta DRE_{cs} \times Z_{cs} + \beta_3 Z_{cs} \\ &\quad + \beta_4 V_{cs2000} + \beta_5 V_{cs1996} + \beta_6 V_{cs1992} + \beta_7 T_{cs2000} \\ &\quad + \beta_8 T_{cs1996} + \beta_9 T_{cs1992} + \beta_{10} X_{cs} + d_s + e_{cs},\end{aligned} \tag{2}$$

where ΔDRE_{cs} is the 2000–2004 change in DRE status and Z is an interaction term. To keep the specification parsimonious, our interaction models restrict the coefficients on DRE in 2000 and 2004 to be equal and opposite in sign. We experiment with many different interaction terms, including the Republican vote share in 2000, the party affiliation of the governor or the secretary of state, whether the state is a swing state, whether the governor is Republican and the state is a swing state (triple interaction), county population, county income, percent black in the county, percent black in the county interacted with whether the state is a swing state (triple interaction), percent Hispanic, and percent college graduates.

C. *Results from Basic Models*

We begin in table 2 by showing changes in election outcomes for every possible combination of voting technology in 2000 and in 2004. The level of observation is a county. The rows refer to the voting technology used in 2000, while the columns refer to the voting technology used in 2004. Entries are the relative change in Republican vote share. The excluded category is represented by counties that have optical voting systems both in 2000 and in 2004. We choose this combination as the baseline, because it is the modal combination. About 30% of counties are in this category.

Counties that switched from lever or optical to touch-screen voting experienced a significant increase in Republican vote share (about 0.4 and 1.8 percentage points, respectively). The opposite is true for counties that switched from punch card to touch-screen. Obviously, the sample size is different in each cell. While almost 3% of counties switch from lever or optical to touch-screen voting, only 0.3% of counties switch from punch cards to touch-screen voting. The effect for counties that switched from paper ballots to DRE does not seem to be statistically significant. Interestingly, a small number of counties (116) used DRE in 2000 and not in 2004. The coefficients for these counties are also mixed.

Having shown how the change in the vote share is related to the full set of technology indicators, we turn to the more parsimonious specification given by equation (1). Table 3 presents a number of variants of this model. The models are

TABLE 2.—CHOICE OF TECHNOLOGY AND THE CHANGE IN REPUBLICAN VOTE SHARE BETWEEN 2000 AND 2004

	Technology in 2004					
	DRE	Optical	Paper	Punch Card	Lever	Unknown
Technology in 2000:						
DRE	0.8	1.3	−4.6	1.1	2.4	−3.4
	(0.2)	(0.4)	(1.9)	(1.1)	(0.5)	(0.4)
Optical scan	0.4	0	−1.7	−0.1	2.4	−2.0
	(0.2)		(0.7)	(0.4)	(0.3)	(0.4)
Paper	0.8	0.5	0.0	0.2	−3.3	−2.0
	(0.7)	(0.4)	(1.2)	(0.8)	(1.8)	(3.3)
Punch card	−3.6	0.5	−2.1	−0.9	1.9	−2.4
	(0.2)	(0.2)	(1.5)	(0.2)	(0.8)	(0.6)
Lever	1.8	−0.6	−6.3	0.1	2.7	0.8
	(0.3)	(0.4)	(1.4)	(0.5)	(0.2)	(0.5)
Unknown	−2.8	−0.2	−1.1	−0.7	0.5	−1.7
	(4.4)	(0.3)	(1.1)	(0.9)	(1.2)	(4.8)

Note: Entries in table are coefficients associated with use of voting technology in row heading in 2000 and voting technology in column heading in 2004, in a model for the change in the Republican vote share between 2000 and 2004. Excluded category is use of optical scan equipment in both years. Model is fit to sample of 3,006 counties. Standard errors in parentheses. Coefficients and standard errors multiplied by 100.

estimated by weighted least squares, using as a weight the county's population in 2000.[22] As a point of departure the model in column 1 regresses the 2000–2004 change in the Republican two-party vote share on indicators for use of touch-screen voting in 2004 and 2000, with only state dummies. The coefficients show a significant *negative* impact of DRE use on the growth in the Republican vote share. The model in column 2 adds controls for the Republican and third-party vote shares in the county in the 1992, 1996, and 2000 federal elections. These lagged vote outcomes—particularly the third-party vote share measures—are very strong predictors of the changes in Republican support between 2000 and 2004. The addition of these controls leads to a positive, although imprecise, DRE coefficient for 2004, and a negative one for 2000.

[22] Unweighted models are generally similar.

In column 3 we present our most complete specification, which includes the lagged vote share variables, state effects, and a total of eight other county-level control variables, all measured in the 2000 Census: percent black, percent Hispanic, percent with a college degree, percent in the military, percent religious adherents, percent working in agriculture, mean personal income, and county population. The addition of these extra controls leads to a very slight increase in the estimated size of the DRE coefficient. The estimated coefficients imply that use of touch-screen technology in 2004 was associated with a 0.25-percentage-point higher Republican share of the two-party vote. The estimate is statistically significant at conventional levels. The corresponding coefficient for 2000 is close to 0, although we cannot reject that the effects in 2000 and 2004 are "equal and opposite" (in other words, that $\beta_1 = -\beta_2$) at conventional significance levels.

TABLE 3.—RELATION BETWEEN CHANGE IN REPUBLICAN VOTE SHARE AND USE OF DRE VOTING TECHNOLOGY: COUNTY-LEVEL MODELS

	(1)	(2)	(3)	(4)	(5)
DRE in 2004 (×100)	−0.44	0.18	0.25	0.26	0.66
	(0.15)	(0.11)	(0.10)	(0.11)	(0.25)
DRE in 2000 (×100)	−0.20	−0.05	0.00	0.03	−0.50
	(0.17)	(0.13)	(0.12)	(0.17)	(0.29)
DRE in 2000 & 2004 (×100)	—	—	—	−0.09	—
				(0.24)	
Republican vote share, 2000	—	0.24	−0.02	0.02	−0.04
		(0.02)	(0.02)	(0.02)	(0.04)
Republican vote share, 1996	—	−0.19	−0.02	−0.02	0.03
		(0.02)	(0.03)	(0.03)	(0.06)
Republican vote share, 1992	—	−0.04	−0.06	−0.06	−0.19
		(0.02)	(0.02)	(0.02)	(0.03)
Third-party vote share, 2000	—	−1.33	−1.03	−1.00	−2.11
		(0.05)	(0.04)	(0.04)	(0.09)
Third-party vote share, 1996	—	0.39	0.01	0.01	−0.57
		(0.03)	(0.03)	(0.03)	(0.07)
Third-party vote share, 1992	—	−0.11	−0.05	−0.05	−0.01
		(0.02)	(0.02)	(0.02)	(0.03)
p-value of test: DRE 2000 = −DRE 2004	0.00	0.41	0.09	—	0.63
State effects	Yes	Yes	Yes	Yes	Yes
County controls	No	No	Yes	Yes	Yes

Note: Standard errors in parentheses. The dependent variable in columns 1–4 is the change in the Republican share of the two-party vote. In column 5 only, the dependent variable is the change in the log share. Sample size is 3,006 in columns 1–2 and 2,914 in columns 3–5. Estimated by weighted least squares using county population in 2000 as a weight. County controls in column 3 are fractions of blacks, Hispanics, college graduates, military employees, agricultural workers, county population, and religious adherents in the county, and median county personal income.

TABLE 4.—RELATION BETWEEN CHANGE IN REPUBLICAN VOTE SHARE AND USE OF DRE IN 2000 AND 2004: STATE-LEVEL MODELS

	(1)	(2)	(3)
DRE in 2004 (×100)	−0.81	0.11	0.99
	(0.99)	(0.95)	(1.02)
DRE in 2000 (×100)	0.66	0.89	−1.20
	(1.68)	(1.45)	(1.61)
p-value of test: DRE 2000 = −DRE 2004	0.32	0.46	0.83
Controls for 1992, 1996, 2000 Republican vote share	No	Yes	Yes
Controls for 1992, 1996, 2000 third-party vote share	No	Yes	Yes
State controls	No	No	Yes

Note: Standard errors in parentheses. The dependent variable is the 2000–2004 change in the Republican share of the two-party vote. Sample size is 49 states. Estimated by weighted least squares using state population in 2000 as a weight. State controls in column 3 are fractions of blacks, Hispanics, college graduates, military employees, agricultural workers, and religious adherents in the state, and average of median county personal incomes in the state.

We have also fit a number of alternative specifications to probe the robustness of our basic models. One variant, shown in column 4 of table 3, adds an interaction term for counties that used touch-screen technology in both 2000 and 2004. Consistent with the simpler specifications reported in column 3, the estimated interaction effect is small and statistically insignificant. In column 5, we used the change in the log of the Republican vote share as a dependent variable. The estimated coefficients from this model provide even stronger evidence that use of DRE technology is associated with the Republican share.[23] Interestingly, the estimates from the log share model are also quite conformable with the hypothesis that the change in the Republican vote share is related to the change in DRE use (p-value of 0.63).

Finally, although not shown in the table, we also fit a specification that included a full set of dummies for the choice of voting technology in the 2000 election (treating optical scanning as the omitted choice). The estimated coefficients from this model are slightly lower than those in column 3 of table 3, but not significantly so: with a 0.18 estimate for DRE in 2004 (standard error = 0.11) and a −0.19 estimate for DRE use in 2000 (standard error = 0.14).

Following the suggestion of a referee, we also investigated whether the effects of DRE adoption are any different if we use cross-state variation instead of within-state variation. Table 4 reports estimates from models in which we regress the statewide change in the Republican share of the two-party vote on the average use of DRE in the state (based on a population-weighted average of the county use rates) and averages of the county-level control variables. The results from the most complete specification (column 3) point to a positive effect of DRE adoption on the Republican share, but the estimates are too imprecise to draw any strong conclusions.

D. *Models with Interactions*

The models in table 3 with the most complete set of controls suggest that use of touch-screen voting in 2004 was associated with a gain the Republican vote share on the order of 0.25 percentage points. This effect would have been large enough to affect the outcomes in some states where the election results were close and touch-screen voting was widely adopted between 2000 and 2004. To better understand the sources of this effect we turn to models that include interactions of the change in the DRE indicator with a variety of state and county-level characteristics. Each row of table 5 presents an alternative version of equation (2) in which we have included our full set of control variables, the change in use of DRE voting, and the interaction of the change in DRE voting with the variable identified in the row heading.[24] We use the change in DRE status, as opposed to DRE status in 2000 and in 2004, for ease of interpretation and because the tests in table 3 suggest that we cannot reject the differenced specification.

Inspection of the estimates in the second column of table 5 suggests that most of interaction terms are either negative or insignificantly different from 0. For example, the coefficient of the interaction with Republican secretary of state is −0.21 percentage points, while the interaction with a Republican governor is 0.23. Neither estimate is statistically different from 0. Similarly, the coefficient of the interaction between change in DRE and swing state status is −0.62 percentage points.[25] The coefficient on the triple interaction between change in DRE, Republican governor, and swing state is also significantly negative. These findings are inconsistent with the hypothesis that touch-screen voting was manipulated by Republican election officials in order to tip the 2004 election in favor of George Bush. We stress, however, that the precision of the estimates of the interaction terms is not very high.

We also report the interactions between the change in DRE status and various county characteristics, including county population, county income, the fractions of blacks and Hispanics in the county, and the percent of county residents with a college degree. Interestingly, there is no evidence that the DRE voting effect is larger (or smaller) in counties with more black or Hispanic residents or college graduates. The interaction with county population is positive. This result is consistent with the hypothesis of rational

[23] The Republican share of the two-party vote is approximately 0.5, on average. The coefficients from the change share model in column 3 suggest that use of DRE in 2004 led to a rise in the vote share of .0025, or a proportional increase of about one-half of one percent. The coefficients from the log share model in column 4 suggest that use of DRE led to a slightly larger proportional rise (about two-thirds of a percent).

[24] Note that the "main effects" of any of the state-level variables used as interactions are absorbed by the state effects included in the model.

[25] We define as swing states those states where the 2000 election was very close and that were predicted to be close races during the summer 2004. The following are swing states: AR, FL, IA, ME, MI, MN, NM, OR, PA, WA, WI, WV.

TABLE 5.—RELATION BETWEEN CHANGE IN REPUBLICAN VOTE SHARE, CHANGE IN USE OF DRE, AND INTERACTIONS OF CHANGE IN USE OF DRE WITH STATE/COUNTY CHARACTERISTICS

	Change in DRE (Main Effect)	Interaction of Change in DRE with Row Variable
	(1)	(2)
No interactions	0.13	—
	(0.08)	
Interacted variable:		
Republican vote share in 2000	−0.37	0.97
	(0.34)	(0.64)
Republican governor	−0.01	0.23
	(0.13)	(0.18)
Republican secretary of state	0.23	−0.21
	(0.18)	(0.18)
Swing state in 2004	0.28	−0.62
	(0.10)	(0.20)
Republican governor × swing state	0.22	−0.81
	(0.09)	(0.27)
Population	−0.33	0.43
	(0.12)	(0.08)
Population × swing state	0.15	−0.21
	(0.09)	(0.20)
Median income/10,000	1.13	−0.34
	(0.31)	(0.10)
Percent black	0.20	0.00
	(0.11)	(0.08)
Percent black × swing state	0.12	−0.01
	(0.09)	(0.02)
Percent Hispanic	0.22	−0.02
	(0.12)	(0.01)
Percent with college degree	0.39	−1.20
	(0.20)	(0.83)
Florida	0.16	−0.52
	(0.09)	(0.33)
Ohio	0.12	−0.17
	(0.08)	(0.80)
Iowa	0.12	−1.53
	(0.08)	(2.47)
New Mexico	0.12	0.25
	(0.08)	(1.29)

Note: Standard errors in parentheses. The dependent variable in all models is the change in the Republican share of the two-party vote. Each row represents a separate model, with change in DRE included as a main effect (coefficient reported in column 1) and interacted with the variable indicated in the row heading (coefficient reported in column 2). All models include the same controls used in column 3 of tables 3 and 4. Models estimated by weighted least squares using county population in 2000 as a weight.

vote manipulation, since it is presumably most effective to manipulate the vote count in larger counties (holding constant the risk of detection). On the other hand, the joint interaction with population and swing state status is insignificant, suggesting that this interpretation is unlikely to be correct.

In the last four rows of the table, we focus on interactions of the change in DRE voting with selected swing states (Florida, Ohio, Iowa, and New Mexico). Although we have shown that the effect of DRE is on average negative when all swing states are considered, it is possible that the effect is different in individual states. Overall, however, the results for the four selected states confirm the picture from our pooled national samples. In the case of Florida, for example, the estimated interaction coefficient is −0.52 percentage points (standard error = 0.33 points). Contrary to the impression conveyed by the analysis by Hout et al. (2004), our model of voting outcomes shows no evidence that Florida counties using DRE technology experienced larger gains for Bush. The interactions effects for the other three states are similarly negative or 0.

To summarize, we find that use of touch-screen voting in a county is associated with a small gain in the Republican vote share in the 2004 election. The precise magnitude of the gain is sensitive to which specific model is adopted, but the estimated effect is significant in our richest specifications which control for state effects, lagged vote shares, and various county-level characteristics. On closer inspection, however, we find no indication that the gain arose in counties or states where one could argue that election officials had the greatest incentive to tip the election in favor of Republicans. Thus, we conclude that the positive association between DRE voting and the Republican vote share does not necessarily reflect direct manipulation of DRE machines by Republican officials.

E. Voter Registration

As a further check for the potential influence of unobserved trends in voter sentiment across counties that happen to be correlated with the adoption of DRE voting, we estimated a series of models for trends in county-level voter registration. Changes in the fraction of voters registered as Republicans presumably reflect the same forces that influence trends in vote shares. However, voter registration patterns are unlikely to be affected by choice of voting technology. Thus, a test for the effect of touch-screen voting on the relative fraction of voters registered as Republicans provides a specification test of our basic regression framework. In particular, the finding of a positive effect of touch-screen voting on the Republican share of registered voters would suggest a spurious correlation between underlying voter preferences and technology choice that could also confound our vote share models.

We collected the data on registration by contacting the secretary of state of each state. A limitation of these data is that not all the states provided data on registration by party. We have only been able to assemble 2004 voter registration data by party for a subset of 1,123 counties (36% of our main sample). The number of counties with 2000 and 2004 registration data is even lower (only 478, or 15% of our main sample).

In order to test whether this subset of counties is representative of the larger sample, we reestimated all the models in table 3 for the limited sample. Results are mixed. Estimates of the DRE coefficients for a model similar to the one in column 3 of table 3 using the subset of 1,123 counties are 0.22 (0.14) for 2004 and 0.37 (0.17) for 2000. Estimates using the subset of 478 counties are 0.61 (0.21) for 2004 and 0.57 (0.28) for 2000. On the other hand, many of the county characteristics are similar in the subsamples and the overall

TABLE 6.—RELATION BETWEEN USE OF DRE AND REPUBLICAN SHARE OF REGISTERED VOTERS

	Republican Share in 2004	Change in Republican Share 2000–2004
	(1)	(2)
DRE in 2004 (×100)	1.49	—
	(0.55)	
Change in DRE (×100)	—	0.09
		(0.50)
State effects	Yes	Yes
Republican vote share 1992–2000	Yes	Yes
Third-party vote share 1992–2000	Yes	Yes
County controls	Yes	Yes
Number of counties	1,123	478

Note: Standard errors in parentheses. Dependent variable in column 1 is the fraction of registered voters who are registered as Republicans in 2004. Dependent variable in column 2 is the change in the Republican share of registered voters between 2000 and 2004. Estimated by weighted least squares using county population in 2000 as a weight.

samples. For example, average income is $27,244 in the full sample, $28,095 in the 1,123-county sample, and $28,974 in the 478-county sample.[26]

The regression models in table 6 take as a dependent variable the fraction of voters registered as Republicans in a county in 2004, or the change in the Republican share of registered voters between 2000 and 2004. For simplicity, we present only our richest specifications, which include state effects, lagged vote shares, and county-level characteristics. The model for the Republican share of registered voters in 2004 (column 1) shows a positive correlation between use of touch-screen voting and the share of voters registered as Republicans. In the differenced specification (column 2), however, the DRE effect drops virtually to 0. Since our vote share models use the change in vote shares as a dependent variable, we interpret the results in table 6 as supportive of the hypothesis that adoption of DRE is unrelated to trends in county-specific preferences for the Republican party. We note, however, that the standard error on the change in DRE effect is large, so we cannot rule out a relationship.

We also reestimated the main models in table 3 controlling for voter registration and including an indicator variable for counties where voter registration is missing. Results do not change significantly. For example, estimates of the coefficient on 2004 and 2000 DRE for a specification like the one in column 3 of table 3 are, respectively, 0.25 (0.10) and −0.01 (0.12).

Finally, we fit a set of models similar to the ones in table 3, but taking as a dependent variable the difference between the change in Republican vote share and the corresponding change in the Republican share of registered voters in a county. By deviating the vote share from the share of registered voters, these models potentially eliminate many of the unobserved components of voter sentiment that could confound the estimated effects of touch-screen voting.[27] Unfortunately, the lack of complete data on voter registration rates presents a problem for this exercise, since as we noted, a "baseline" model gives rise to estimated DRE effects that are somewhat different from the estimates over the full sample of counties. Nevertheless, models for the change in the vote share relative to the change in the Republican share of registered voters show a positive and marginally significant effect of DRE use in 2004 on the change in the Republican vote share relative to the change in the Republican share of registered voters between 2000 and 2004. (Estimates are available on request.) Given the limitation of the registration data, however, it is difficult to draw strong conclusions from these estimates.

IV. Models of Turnout and DRE Adoption

A. *Overview*

So far we have focused on the effect of voting technology on the share of Republican votes, effectively conditioning on the sample of citizens who go to the polls and whose vote is recorded as valid. We have shown that there is a small positive effect of touch-screen voting technology on the level of electoral support for George W. Bush. Looking at models that interact the use of DRE with county-level characteristics, however, we conclude that this finding is unlikely to be explained by systematic voting irregularities on the part of Republican election officials. If the DRE effect cannot be explained by voting irregularities, why is there a relationship between DRE technology and the share of votes for Bush? Part of the explanation may be a spurious correlation between underlying trends in voter preferences and choice of voting technology (although our voter registration models provide no evidence of this). An alternative explanation that we explore in this section is that the adoption of electronic voting technology affects the mix of voters at the polls, or the composition of the ballots that are counted as valid, leading to a shift in the fraction of votes for a Republican candidate.

There are (at least) three reasons that the adoption of touch-screen voting technology could affect the relative turnout rates of different voter subgroups. First, electronic voting machines may be perceived as confusing or intimidating by subgroups that have limited familiarity with computers or ATM machines. Second, some minority groups, especially African-Americans, may be particularly suspicious of electronic voting technology, given the allegations surrounding this technology and the many historical episodes of disenfranchisement of African-American voters.

[26] Similarly, the fractions of blacks are 12.1%, 11.4%, and 11.2%, respectively, in the three samples, while the fractions of college graduates are 20.3%, 21.0%, and 21.5%, and the fractions of religious adherents are 50.3%, 50.1%, and 50.1%.

[27] Voters may not necessarily switch their party of registration, even when they have firmly realigned their election preferences. Thus, the level or trend in voter registration is at best only a partial control for voter sentiment.

Third, it is possible that use of electronic voting technology changes the length of queues at polling stations, affecting the voting propensity of potential voters who are most likely to try to vote at "peak" times.

Different voting technologies may also affect the relative fraction of votes cast by different demographic groups that are ultimately recorded as valid. Previous studies that have attempted to directly link electronic voting to the relative fractions of valid votes cast by different groups have reached a mixed conclusion.[28] Since we define voter turnout as the ratio of *valid* votes cast to county population, our analysis of the effect of DRE technology on turnout includes both the "direct" effect of electronic voting on the number of voters who go to the polls (if any), and the "indirect" effect on the number of votes that are counted as invalid (if any). In the absence of comprehensive data on the number of invalid votes by county, we do not attempt to separate these two margins.

In order to better understand how voting technology may affect electoral outcomes through its effect on turnout, consider the following simplified model. Let the total number of voters in a county, V, include minority voters (V^m) and others (V^o). If S is the Republican share of votes in a county, and S^m and S^o are the vote shares for the two groups, then $S = S^mV^m + S^oV^o$. A "mechanical" effect of relative turnout on voting outcomes arises if minorities (or some other group whose turnout is differentially affected by voting technology) tend to vote differently than other voters (that is, if $S^m \neq S^o$). Let t^m and t^o denote the turnout rates of minority and nonminority voters, and let f^m denote the fraction of minorities in the voter-eligible population. Suppose that voter turnout rates of the two groups are related to a set of county-level covariates X by a pair of linear regression models of the form: $t^o = a_o + b_oX$ and $t^m = a_m + b_mX$, where X includes an indicator for DRE voting. Then the implied regression model for overall turnout is

$$t = a_o + (a_m - a_o) f^m + (b_m - b_o) f^m X + e,$$

where e represents a residual term. The coefficient on the interaction term f^mX in this model identifies the relative effect of X on the turnout rates of minority and nonminority voters. Using this setup, it can be easily shown that the "mechanical" effect of X on the Republican vote share in a county is

$$\partial S/\partial X = (S^m - S^o) \times f^m(1 - f^m)/t \times (b_m - b_o). \qquad (3)$$

The impact of DRE technology on the Republican vote share therefore depends on the difference in voter preferences between minorities and others conditional on casting a valid vote, and on differential effect of DRE voting on turnout rates. The latter can be estimated as the interaction term between DRE and minority share in a county-level turnout model.

[28] See Tomz and Van Houweling (2003) for a succinct summary of the existing evidence on the link between voting technology and the racial gap in invalid votes.

TABLE 7.—RELATION BETWEEN DIRECT ELECTRONIC RECORDING VOTING TECHNOLOGY AND VOTER TURNOUT

	Turnout in 2004	Change in Turnout from 2000 to 2004	
	(1)	(2)	(3)
DRE in 2004 (×100)	−1.40 (0.28)	—	—
Change in DRE (×100)	—	−0.71 (0.14)	0.02 (0.24)
Change in DRE × share black (×100)	—	—	−0.01 (0.01)
Change in DRE × share Hispanics (×100)	—	—	−0.04 (0.01)
State effects	Yes	Yes	Yes
Republican vote share 1992–2000	Yes	Yes	Yes
Third-party vote share 1992–2000	Yes	Yes	Yes
County controls	Yes	Yes	Yes

Note: Standard errors in parentheses. Dependent variable in column 1 is estimated voter turnout in 2004 (number of votes cast/total county population). Dependent variable in columns 2 and 3 is change in estimated voter turnout between 2000 and 2004. Estimated by weighted least squares using the county population in 2000 as a weight.

B. *Estimates of the Effect of Touch-Screen Voting on Voter Turnout*

Table 7 presents a set of models in which the dependent variable is either a measure of voter turnout in a county in the 2004 election, or the change in the measure between 2000 and 2004.[29] For simplicity, we present only our richest specifications, which include state effects, lagged vote shares, and county-level controls. Note first that the level of turnout is negatively correlated with use of DRE, with the estimate implying a 1.4 percentage point reduction in turnout in counties that used DRE in 2004 (column 1). The corresponding estimate from an unweighted model is −1.23 (0.44). A potential limitation of this cross-sectional estimate is that it may fail to control for unobserved county-level factors that could affect turnout (such as the age structure of the population, or the fraction of noncitizen immigrants).

In the model that regresses the change in turnout on the change in DRE use, we also find a negative and significant effect of DRE use in the weighted model (column 2). This estimate therefore suggests that adoption of touch-screen voting leads to a decline in voter turnout. The effect is of moderate size. It indicates that turnout in counties that have adopted DRE in 2004 is about 0.7 percentage points lower

[29] We define turnout as the ratio between the total number of valid votes counted and county population. Ideally, turnout should be defined as the ratio of the number of votes cast to the size of the eligible population. By dividing by the total population we ignore differences across counties in the fraction of people under the age of eighteen, and in the fraction of those eighteen and older who are ineligible (McDonald & Popkin, 2001).

than in observationally similar counties that have not adopted.

A possible interpretation of this estimate is that the introduction of touch-screen voting machine reduces participation among some group of voters (or lowers the fraction of valid votes recorded). We are particularly interested in the effect for minorities. We therefore estimate a model for the change in voter turnout that includes the change in DRE status, and its interaction with the fraction of blacks or Hispanics in the county, as well as the main effects. As shown in column 3 of table 7, we find no significant interactions with the fraction of blacks in a county, but the interaction with the fraction of Hispanics is negative and significant: −0.04. This effect implies that the turnout rate is reduced by 0.04 percentage points more by the presence of DRE voting technology in a county where 10% of the population is Hispanic than in a county where there are no Hispanics. One possible interpretation of this finding is that the introduction of DRE reduces Hispanic participation in presidential elections because it intimidates potential Hispanic voters or because potential Hispanic voters distrust it. Another interpretation is that DRE voting reduces the number of valid votes because of limited English proficiency or other cultural barrier that make it difficult for Hispanics to deal with ATM-style machines.[30]

To sum up: we find that DRE adoption is associated with lower turnout rates, particularly in counties with a large share of Hispanics. Since Hispanic voters tend to favor Democrats, this interaction effect is potentially important. In particular, exit poll data indicate that in 2004 55% Hispanic voters supported Kerry while 45% supported Bush.[31] Florida is an exception. Presumably because of the Cuban vote, exit poll data suggest that Florida Hispanics voted 56% in favor of Bush. How large is the potential turnout effect on election outcomes? We can use equation (3) to obtain an approximate answer. Taking the national exit poll estimate of $(S^h - S^o) = -0.10$, and assuming the fraction of Hispanics in the potential voting pool is 6%, and the average turnout rate is 70%, we have to multiply the interaction term by −0.008 to get an implied effect on vote shares. Based on the estimates in table 7, the effect on Republican vote share is likely to be very small: on the order of 0.00032 (= −0.008 × −0.04) or 0.03 percent. If we compare this number with the coefficient in column 4 of table 3 (0.21) we conclude that the turnout mechanism can explain only about 14% (0.03/0.21 = 0.14) of the overall effect of touch-screen voting on the Republican vote share.

C. *Is DRE More Likely to Be Adopted in Counties with More Minorities?*

In the previous subsection, we have shown that touch-screen voting is associated with lower turnout rates, particularly in counties with a large share of Hispanics. Given that Hispanics tend to vote Democrat, the obvious next question is whether there is evidence that this relationship might have been used strategically to favor the Republican candidate. Specifically, in this subsection we look at models in which DRE adoption is the dependent variable. The models include the fraction of Hispanics in a county, interactions of the fraction of Hispanics with indicators for whether the state was a swing state in 2000, and whether the state governor is Republican, as well as all the other controls. The idea is that if DRE adoption between 2000 and 2004 was used strategically to help the Republican candidate, we should see four features in the data. First, we should see that DRE adoption is more likely in counties with more Hispanics, everything else constant. Second, we should see that the association between the fraction of Hispanics and DRE adoption is stronger in states that were swing states in 2000. Third, we should see that the association between the fraction of Hispanics and DRE adoption is also stronger in states that were controlled by Republicans in 2000. Finally, we should find little relationship between DRE adoption and fraction of Hispanics in Florida, since Hispanics in Florida are more likely to vote for Republican candidates.

Table 8 presents estimates from models where the dependent variable is the 2000–2004 change in use of DRE technology. For simplicity, we report only selected coefficients, although all the usual county-level controls are included, as well as state effects in the models in columns 4–6. Moreover, in the models with interaction effects we always include the associated main effects. The estimates in columns 1 and 3 suggest that DRE adoption is higher in counties with a larger fraction of Hispanic residents. To aid in the interpretation of the Hispanic coefficient in these models, note that the standard deviation in the fraction of Hispanics across counties is 12 percentage points. Thus, the estimate in column 4 of table 8 implies that a standard-deviation increase in the share of Hispanics in a county is associated with 3.4-percentage-point increase in the probability of adopting DRE technology. By comparison, there is no significant effect of a higher black population.

Obviously, we do not know whether the correlation between percent Hispanic and DRE adoption is accidental or reflects strategic behavior on the part of election officials. But the models in columns 2 and 5 indicate that when fraction Hispanic is interacted with a dummy for whether

[30] We have also estimated models that include a triple interaction of change in DRE, percent Hispanic and an indicator for swing states, as well as controls for all the pairwise interactions (change in DRE × Hispanic, change in DRE × swing state, swing state × Hispanic). The coefficient on change in DRE × Hispanic does not change very much: −0.037 (0.009), confirming that the negative effect of DRE on turnout is larger for more Hispanic counties. The coefficient on the triple interaction is −0.045 (0.036), possibly suggesting that the larger negative effect of the DRE on turnout for more Hispanic counties is magnified in swing states, although the coefficient is not statistically significant.

[31] National and state-level exit poll data are reported at http://www.cnn.com/ELECTION/2004/pages/results/states/US/P/00/epolls.0.html. This source also provides estimates of the share of different demographic groups in the pool of voters.

TABLE 8.—DETERMINANTS OF THE ADOPTION OF DIRECT ELECTRONIC RECORDING VOTING TECHNOLOGY

	(1)	(2)	(3)	(4)	(5)	(6)
Fraction Hispanic	0.17	0.11	0.31	0.28	0.21	0.27
	(0.07)	(0.07)	(0.16)	(0.07)	(0.07)	(0.21)
Hispanic × swing 2000		0.48			0.92	
		(0.21)			(0.30)	
Hispanic × Republican governor			−0.21			0.01
			(0.16)			(0.22)
Fraction black	0.09	−0.02	−0.09	−0.04	−0.25	0.12
	(0.08)	(0.08)	(0.10)	(0.08)	(0.09)	(0.11)
Black × swing 2000		0.58			0.81	
		(0.16)			(0.16)	
Black × Republican governor			0.29			−0.32
			(0.13)			(0.14)
State fixed effects	No	No	No	Yes	Yes	Yes
County controls	Yes	Yes	Yes	Yes	Yes	Yes

Note: Standard errors in parentheses. Dependent variable in all models is the difference in indicators for use of DRE technology from 2000 to 2004. Estimates by weighted least squares using county population in 2000 as weights. Models with interactions also include the main effects of all interacted variables.

the state was a swing state in 2000, the coefficient is positive and statistically significant. In column 5, for example, the Hispanic main effect is 0.21, while the coefficient on the interaction between Hispanic and swing state is 0.92. This means that for counties located in swing states, the relation between Hispanics and DRE is four or five times larger than for counties not located in swing states. This finding would appear to be consistent with the notion that touch-screen voting was systematically adopted to reduce swing states' voter turnout rates of a minority group that is more likely to vote Democrat.

On the other hand, the results in columns 3 and 6 indicate that the relationship between minorities and DRE adoption was not systematically stronger in states controlled by Republican governors. Moreover, when we look at the triple interaction between Hispanic, swing state status, and Republican governor (not in the table), we find an insignificant positive effect (0.27, with a standard error of 0.65) in our preferred model with state effects. Finally, when we look at Florida, we find that the coefficient on Hispanic is not statistically significant from 0, although the standard error is relatively large (0.77), reflecting the modest number of counties in the state.

Overall, we draw three conclusions. First, DRE adoption is significantly negatively related to turnout rates, with an effect that is larger in counties with a larger share of Hispanic residents. Second, the net effect on electoral outcomes is small. Our analysis suggests that the relative effect on Hispanic turnout explains at most a 0.03-percentage-point increase in the Republican vote share, or about 14% of the overall difference in Republican vote shares between DRE and non-DRE counties. Third, DRE adoption appears to have been more likely in counties with a larger share of Hispanic residents, particularly in swing states, although not in states controlled by a Republican governor. Thus, evidence for the hypothesis of strategic DRE adoption is mixed.

V. Conclusions

Touch-screen voting has attracted an enormous amount of attention and controversy. Numerous allegations have been raised concerning the reliability of touch-screen voting equipment and the possibility of vote tampering. The distrust in electronic voting is shared by the mainstream press and some members of Congress, and is substantiated by peer-reviewed academic studies. If the controversy cannot be resolved, one consequence may be a further deepening of the public distrust in the electoral and democratic system.

While there have been many allegations of specific instances of irregularities, there has been surprisingly little systematic empirical evidence on voting irregularities associated with changes in voting technology. In this paper, we use county-level data on voting technology and election outcomes in the 2000 and 2004 presidential elections to try to determine whether there is evidence of systematic voting manipulations associated with electronic voting. Our results suggest that electronic voting has a small effect on election outcomes, but that the mechanism is not illegal vote manipulation.

We first show that there is a small positive correlation between adoption of touch-screen voting technology and the level of electoral support for George Bush. In particular, we find that between 2000 and 2004, the Republican vote share increased more in counties that adopted touch-screen voting than in counties that did not. Although small, this effect would have been large enough to influence the final result in some closely contested states (for example, Ohio), and therefore the final election outcome.

On the surface this finding would appear to be consistent with some of the allegations of voting irregularities associated with touch-screen voting technology that were raised at the time of the 2004 elections. However, a closer examination of the evidence suggests that this interpretation is implausible. If irregularities did take place, they would be most likely in counties that could potentially affect statewide election totals, or in counties where election officials had incentives to affect the results. To test this prediction, we fit a series of models that include indicators for use of touch-screen technology and the interaction of these indicators with indicators for whether the state was a swing state, or whether the secretary of state (or the governor) was Republican. We find no evidence that these interaction effects are positive. Indeed, if anything, the touch-screen voting effect is smaller in swing states, and in states with a Republican secretary of state or governor.

We also find that voting technology can affect electoral outcomes indirectly, through an effect on turnout. Specifically, we find that touch-screen voting is associated with lower turnout rates, especially in counties with a larger share of Hispanic residents. By changing the mix of voters who go to the polls (or the mix of voters who cast a valid vote), this turnout effect could ultimately influence election outcomes. Moreover, we find that counties with a larger fraction of Hispanics are more likely to adopt touch-screen technology, particularly in swing states (although not in states controlled by a Republican governor). Regardless of the source of this correlation, however, its effect on election outcomes is small, accounting for only 15% of the apparent gain in the Republican vote share in counties that used touch-screen voting in 2004.

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