

## Why chads? Determinants of voting equipment use in the United States

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**Abstract.** This paper provides an empirical study of the determinants of voting equipment choice in the United States. We document that, in contrast to widespread belief, voting machines of older types, such as lever and punchcard systems, are not used in counties with lower income – and newer machines, such as optical scanners and electronic machines, are not used in – richer counties. We provide an economic explanation for this and other regularities of voting equipment usage in the United States. In our economic framework (a) the adoption of a new technology is more likely in richer and larger counties, but (b) the adoption of a new technology is less likely the more advanced is the technology already adopted in the county. The adoption of more advanced optical and electronic machines in the 1980s and 1990s was less likely in richer and larger counties that had already mechanized and computerized in previous decades than in poorer and smaller – and hence not yet computerized counties. Estimates of historical determinants of voting equipment choice support our hypothesis. In particular, the probability of using punchcard machines in the 1990s is positively related to a county's income in the 1960s, when punchcard machines were first introduced. When the effect of past income is controlled for, the effect of more recent levels of income on the probability of using punchcard machines becomes negative.

### Introduction

The bizarre turn of events that followed the November 7, 2000 presidential election brought unprecedented attention to the use of different voting equipment in the United States. In particular, the reading of punchcard ballots in a few Florida counties became the subject of heated legal disputes that ended with a controversial U.S. Supreme Court ruling on December 12, 2000. During the Florida crisis the media were filled with detailed reports on the mechanics of different voting equipment. Colorful expressions, such as 'hanging chads' and 'pregnant chads,' entered the national vocabulary.<sup>1</sup> That crisis has spurred an ongoing debate on voting equipment choice and election reform. Proposals to develop national or state standards for conducting elections and to fund voting equipment upgrades have been introduced in the U.S. Congress and in numerous state capitals. In December 2001 an election reform bill was passed in the House, whereas the Senate passed one 4 months later. More recently, problems with voting equipment during Florida's September 2002 primary elections have brought the issue

back in the news. Political commentators have stressed the continuous relevance of the “machinery in which [elected officials’] own legitimacy is grounded.”<sup>2</sup>

Although voting equipment has received widespread attention in the media and in the political debate, the fundamental question of why different counties in the United States happen to use different voting equipments has been left unanswered. This paper presents, to the best of our knowledge, the first systematic study of the determinants of voting equipment choice in the United States. We will document some paradoxical features of the current distribution of voting equipment in the United States and will develop an economic framework that will explain such paradoxes as the natural outcome of dynamic choices over time. We will then provide historical evidence consistent with our economic explanation.

A striking aspect of voting equipment usage in the United States is its heterogeneity. All sorts of systems are used across the nation. American voters mark paper ballots, pull levers, punch cards, fill optically-readable forms, or touch electronic screens. Data obtained from Election Data Services (EDS) show the following distribution of voting equipment types across counties in 1999: optical scanners 38.8% of counties; punchcard machines 20.2%; electronic machines 8.2%; lever machines 15.3%; paper ballots 13.1%. The distribution as a percentage of registered voters was: Punchcard machines 34.1%; optical 27.6%; lever 18.5%; electronic 9.1%; paper 1.6%.<sup>3</sup>

The machines currently in use are based on technologies spanning over a century. Optical and electronic machines have been adopted since the late 1970s. Punchcard voting machines were first introduced in 1964. Lever machines were first used in statewide elections in 1892. In fact, virtually *each* type of voting equipment ever introduced in the United States since the 19th century is still used somewhere in the country.<sup>4</sup> More detailed information on the history and characteristics of voting equipment is reported in section on “types of voting equipment in the United States.”

Such heterogeneity is partly the result of decentralization. Although many other democracies have unified national voting systems, in the United States choices over voting equipment are highly decentralized – mostly at the county and municipal level.<sup>5</sup> This situation raises an important question: What explains the use of different voting equipment? Why do some counties use punchcard machines (or even older lever machines, or just paper ballots), whereas other counties use more advanced optical scanners or electronic machines? In a nutshell, Why Chads?

The question is worth addressing by economists for at least two reasons:

1. Voting equipment matters. Although the Supreme Court decision in December 2000 ended the legal battle over the recounting of votes in a few Florida counties, the debate over the causes and consequences of

voting equipment choice is not over, and will resurface in future elections in the United States. Such debate can certainly benefit from more accurate and systematic information about the determinants of voting equipment use.

2. By learning about the determinants of voting equipment use across United States counties, we can obtain more general insights on the adoption of innovation by public authorities. For decades all over the United States local authorities have quietly run a fascinating natural experiment on the adoption of technological innovation in vote-tallying. From it economists may obtain useful information about the way innovations in general are (or are not) adopted across different jurisdictions.

Why do some counties use older voting machines whereas others use more updated ones? Vice-President Al Gore among others suggested that those differences reflect economic inequality:

“The old and cheap, outdated machinery is usually found in areas with populations that are of lower income, minorities, seniors on fixed incomes.” (Gore, 2000)

The view that older machinery is used in poorer counties is intuitively appealing, and has been widely reported in the media. For example, according to *The Economist* (June 9, 2001, p. 32) “everybody knows that the worst voting machinery is concentrated in poor areas.” Somewhat surprisingly, such widespread belief does not seem to be consistent with the data on the distribution of voting equipment types across counties. In the third section we show that, on average, machines of older types are not used in relatively poorer counties. When data on voting equipment from EDS are matched with the most recent census data, one finds that the median household income in counties using lever and punchcard machines (the older machinery) is higher than in counties using optical scanners or electronic machines (the newer machinery). Also, summary statistics do not provide *prima facie* evidence that machines of older types are disproportionately used in counties with larger minorities or older population.

In the third section we also present logit regressions with different types of equipment as dependent variables. This more formal analysis is consistent with the patterns suggested by the summary statistics. Specifically, we find evidence against the hypothesis that lower income increases the probability of using lever or punchcard machines rather than optical scanners or electronic machines, controlling for other potential determinants of voting equipment choice. If anything, richer counties seem to be more likely to use machines of older type.

Is there a “paradox of chads”? Should we be surprised to find out that many richer counties use older technology, such as punchcard machines, whereas

a large number of relatively poorer ones have switched to more advanced machinery? Does this mean that economic factors have played no role in the choice of voting equipment over time?

As we will see, our findings are that economic factors *did* play a key role in the determination of voting equipment choice, but not in the naive, “static” way underlying most observers’ beliefs. The “chads paradox” can be explained by taking into account the dynamic nature of voting equipment choice. In other words, as we will see, economic factors matter and *history matters*.

Specifically, our explanation hinges on two points:

1. all other things equal, a richer county is more likely to adopt a more advanced technology, but
2. among all things that must be equal we should include the county’s current technology.

If the richer county has already adopted a more advanced technology in the past, it will benefit less from adopting and even more advanced technology in the future, whereas the adoption of the newest technology will have the highest benefits in counties that are still using much older technology. As a consequence, richer counties may be leapfrogged by poorer counties.

The fourth section presents a model that is consistent with these ideas. The model is consistent with a positive relationship between current income and use of older machinery. However, the model predicts that, once past income has been controlled for, the relationship between current income and use of older machinery should be negative.

The fifth section examines whether the available empirical evidence is consistent with our hypotheses. First, we show that between 1980 and 2000 the share of counties that used optical or electronic machines went from 1% to 49.1%. The transition took place through reductions in the number of counties that used paper ballots (from 40.4% to 12.5%) or lever machines (from 36.4% to 14.7%). By contrast, the share of counties that used punchcard machines barely moved (19.1 v. 19.2). This pattern is consistent with our story.

To provide a more direct and formal test of our hypothesis, in fifth section we also present logit estimates using past values for income. The results provide support for our model. We find that:

1. Income in 1969 has a positive effect on the probability of using older equipment in 1999. In the case of punchcards, such effect is one order of magnitude larger than the effect of 1989 income when one does not control for 1969 income.

2. When income in 1969 is included in the regression, the effect of income in 1989 becomes *negative* (for punchcard machines) or insignificant (for lever plus punchcard).

In other words, the positive correlation between most recent income and use of older equipment is explained by the positive correlation between most recent income and past income. When past income is explicitly taken into account, the effect of current income – as predicted by our model – becomes negative or insignificant.

Hence our analysis provides a consistent explanation for the “paradox of chads.” ‘Chads’ are found in counties that used to be richer in the 1960s, when punchcard machines were adopted – and, therefore, on average, are still likely to be richer today. When past income is controlled for, a “nonparadoxical” negative relationship between present income and use of older, outdated equipment emerges.

In the sixth section, we extend the analysis to explicitly include another important variable along with income: population size. We argue that, all other things equal, a larger population increases the probability of adopting more advanced voting technology. The aggregate cost of adopting a new technology includes a significant fixed component, which is independent of size. Henceforth, cost per capita is decreasing in the size of a county. Moreover, benefits from adopting more advanced technology may be positively related to total size (for example, the benefits from speedy vote-tallying may be higher in larger counties). Does this imply that larger counties – controlling for income – will be more likely to use more advanced technology? No, for the same reasons why a higher income does not guarantee a better technology. Section 6 contains an empirical analysis of the relationship between historical levels of population and current usage of voting equipment. The results are consistent with our general point. The probability of using lever machines in 1999 is *positively* related to population in 1930 (when larger counties were more likely to adopt state-of-the-art lever machines), but negatively related to population in 1990, when larger counties were more likely to adopt more advanced electronic machines, other things being equal. By the same token, the probability of using punchcard machines is negatively related to population in 1930, but positively related to population in 1970, when punchcard machines were being adopted.

Finally, a word of clarification about the purpose and limits of our analysis. Most of the post-Florida literature on vote counting has focused on the political and civil-rights *consequences* of heterogeneity in voting equipment distribution. Recent studies have addressed the important issue of whether the distribution of voting equipment has resulted in the undercount of the votes cast by specific groups (individuals with lower income, Democrats, minorities). For example, Lott (2003) studies the presidential vote in Florida and finds that

voting equipment is important to explain spoiled (or nonvoted) ballot rates, but that the poor were not more likely to have their votes not counted. He also finds little evidence of discrimination toward African American Democrat voters with respect to non-voted ballots. Knack and Kropf (2003) examine the 1996 presidential election and find that voided ballots are more prevalent in counties with higher percentages of African Americans, but that the relationship disappears in counties using voting equipment that can be programmed to eliminate overvoting. They find that the highest rates of voided ballots are associated with punchcard machines, whereas the lowest is associated with lever machines. In a different study (Knack and Kropf, 2002), the same authors find that it is white, the non-poor and Republican voters who are more likely to reside in counties with punchcard machines. Our paper differs from these studies. We do not investigate the *implications* of a given voting equipment distribution for voters with different economic, ethnic and political characteristics. This paper is instead about the *causes* of the distribution of voting equipment technologies. In particular, we provide the first economic analysis of the dynamics of voting equipment adoption, emphasizing economic and demographic factors as key determinants of the voting equipment *choice*. In other words in our paper, unlike in other contributions, the adoption of voting technology is the key *endogenous* variable, to be understood is the outcome of public choices. An accurate understanding of the historical dynamics that has led to the current distribution of voting equipment is important not only *per se*, but also to derive better-informed policy prescriptions when upgrade of existing voting equipment is high on the agenda. For example, by simply observing that, on average, poorer counties do not have ‘worse’ voting technology, one could erroneously conclude that economic resources are not a factor in voting equipment choice – a misconception that could lead to incorrect policy advice. By contrast, our analysis clarifies the paradox of inferior technology in richer counties by pointing out that economic factors *did* play a key role in the dynamic process of voting equipment choice, and that *given* existing technology, counties with higher income are indeed more likely to adopt more advanced voting technology.

In summary, the strikingly heterogeneous distribution of voting equipment in the United States can be best understood as reflecting an intriguing “archeology” of historical decisions and trends. In a way, the political economy of voting equipment is like a time machine. New York and Connecticut’s antique lever machines mirrors the past economic and demographic preeminence of the Northeast. Punchcard machines in Atlanta, Los Angeles, and Miami witness the expansion of those regions after the Second World War. The electronic machines of New Mexico speak about today’s economic and demographic realities. As economists interested in public choice and adoption of technological innovation over time, we have found such history fascinating and worth telling.

### Types of Voting Equipment in the United States

As reported by EDS, as of April 1, 1999, the 3141 U.S. counties used five different systems to count votes:

1. Paper ballots: 407 counties;
2. Lever machines: 476 counties;
3. Punchcard machines: 625 counties;
4. Optical scanners: 1231 counties;
5. Electronic machines: 261 counties.

The remaining 141 counties used mixed systems.<sup>6</sup>

The paper ballot system is the oldest method.<sup>7</sup> It was first adopted in Australia in 1856, and introduced in the United States in the second half of the 19th century. In its current form, the paper ballot system employs uniform official ballots on which the names of all candidates are printed. Voters privately record their choices by marking the boxes next to the candidate they select and drop the voted ballot in a sealed ballot box. Many industrial democracies, including Canada and Italy, use paper ballots as their exclusive voting system.

Lever machines were first employed in Lockport, New York in 1892, and were adopted statewide a few years later. According to the Federal Election Committee (2001) “by 1930, lever machines had been installed in virtually every major city in the United States, and by the 1960s well over half of the Nation’s votes were being cast on these machines.” On lever machines, each candidate is assigned a lever identified by a printed strip. Voters pull down selected levers to indicate choice. When the voter exits the booth, the voted levers are automatically returned to their original position, causing a connected counter wheel to turn. The position of each counter at the close of the polls indicates the number of votes cast on the lever that drives it. Lever machines are no longer made. According to the Federal Election Commission, “the trend is to replace them with computer-based marksense or direct recording electronic systems.”

Punchcard voting systems were first used in 1964 by Fulton and De Kalb Counties (Georgia), Lane County (Oregon) and San Joaquin and Monterey Counties (California). Voters punch holes in the card with a supplied pin. The resulting leftover piece of paper is referred to as a chad (a term of unknown origin).<sup>8</sup> With votomatic cards, the locations at which holes may be punched are assigned numbers. With datavote cards the name of the candidate is printed on the ballot next to the hole to be punched.<sup>9</sup> After voters have punched their cards, ballots are fed into a computer vote-tabulating device.

Optical scanners recognize marks on paper through optical reading techniques. Voters record their choices by filling in a rectangle, circle, or oval. The tabulating device reads the votes using “dark mark logic” (i.e., by

selecting the darkest mark within a given set). Optical scanned ballots have been adopted in the United States since the 1970s. Optical scanners (also known as “marksense optical scan systems”) are currently considered “state-of-the-art” voting technology, and directly compete with the last type of voting system, electronic machines. With electronic machines (also known as “direct recording electronic” systems, or DRE), the voter directly enters choice with the use of a touch-screen or similar device. The voter’s choice are electronically stored via a memory cartridge, diskette, or smart card.

Until the early 1970s there existed no national standards on voting equipment. In 1975 the General Accounting Office’s Office of Federal Elections sponsored an influential report (*Effective use of computing technology in vote-tallying*) which called for more computerization. In 1984 the federal government issued a report on the *Feasibility of developing voluntary standards for voting equipment* (Federal Election Commission and National Institute of Standards and Technology, 1984). In a subsequent report, also sponsored by Federal Election Commission and the National Institute of Standards and Technology, Saltman (1988) recommended to phase out punchcard machines in favor of optical scanners and electronic machines. In 1990, the Federal Election Commission proposed the first national performance and test standards for punchcard, optical, and electronic voting systems. Decisions on whether to follow the Commission’s guidelines and on the actual choice of voting equipment were left to local officials. The recent events in Florida have highlighted one of the technical problems with punchcard machines, that is, the possibility of “undercount” because of imperfectly displaced chads. The relative merits of optical scanners and electronic systems are currently debated by experts and politicians.<sup>10</sup> Both systems are currently purchased by U.S. local officials. A recent study by Ansolabehere et al. (2001), issued as part of the Caltech/MIT Voting Technology Project, has used “residual votes” (i.e., ballots cast for which no presidential preference was counted) as yardstick for “reliability,” and has concluded that paper ballots, lever machines and optical scanners are more “reliable” (i.e., less likely to produce uncounted ballots) than punchcard machines and electronic machines. In fact, the oldest system of all, paper ballots, seems to be the most reliable. We will return on these issues in the fourth section, when we model the adoption of voting equipment by county officials.

### **Determinants of Voting Equipment Use: A Preliminary Analysis**

As a first step toward understanding the determinants of voting equipment choice, we consider the following county characteristics:

1. median household income (1989);
2. population (1990);
3. % Population 65 years or older (1990);
4. % Population classified as minorities (1990);
5. % Population 25 percent or older with Bachelor's degree or higher (1990);
6. local government revenues per capita (1986–1997).

The summary statistics for these variables are reported in Table 1.

Average median household income in 1989 was \$28,817 in counties with lever machines, \$30,584 in counties with punchcard machines, \$28,124 in counties with optical scanners, and \$27,992 in counties with electronic machines. That is, lever and punchcard systems are used in counties with incomes above the average median income for all counties. By contrast, median income in counties that use optical or electronic is (slightly) below average. The lowest income is found in counties that use paper ballots (\$24,799).

The summary statistics also show that punchcard counties, on average, have a substantially larger population (1,40,007 inhabitants vs. an average for all counties equal to 79,182 inhabitants). Counties that use lever and electronic machines also have populations larger than average, although the difference is not as large as in punchcard counties. By contrast, counties that use optical scanners are smaller (54,601 inhabitants) than average.

The percentage of minorities is higher (19.8%) in counties that use levers, and lower in counties that used punchcard machines (12.5%), when compared with optical and electronic (17.7% and 16.7%, respectively). The percentage is also lower for paper ballots (11.4%). The percentage of seniors is 18% in

*Table 1.* Summary statistics

	All counties	Paper	Lever	Punch	Optical	Elect.	Lever/ Punch	Elec./ Opt.
Median income 89	28475	24799	28817	30584	28124	27992	29890	28088
Population 1990	79182	8869	96615	140007	54601	92282	121247	61193
% Age 65+	15	18	14	14	15	13	14	15
% Minority	15.5	11.4	19.8	12.5	17.7	16.7	15.7	17.5
% Bachelor	14	12	13	14	14	13	14	14
Local Govt \$/cap	1446	1707	1305	1374	1506	1144	1344	1442

Number of counties = 3141.

Number of counties, paper = 407.

Number of counties, lever = 476.

Number of counties, punch = 625.

Number of counties, optical = 1231.

Number of counties, electronic = 261.

Number of counties, mixed = 141.

counties with paper ballots, 14% in counties with levers and optical, 15% in counties with optical, and 13% in counties with electronic.

To investigate systematically the relationship between voting methods and county characteristics, we have performed logit estimations (Tables 2–4). Logit estimates with each type of counting method as dependant variable are reported in Tables 2a–2d. In each table, column (i) shows estimates when only income and population are used as independent variables. In column (ii) we add additional controls (seniors, minorities, population with bachelor’s population, all as percentages of the population, plus local government revenues per capita).<sup>11</sup> In Table 2, we show logit estimates when we aggregate lever and punchcard machines. In Table 2f we show logit estimates when we ask what is the probability of using lever and punchcard machines versus optical and electronic (i.e., we drop paper ballots from the sample). Multinomial logit estimates are shown in Tables 3 and 4. Table 3 reports multinomial logit estimates using punchcard as the base group of comparison. Table 4 reports multinomial logit estimates using punch/lever as the base group.<sup>12</sup>

Overall, the logit estimates tend to confirm the regularities one can detect from the summary statistics.

- a) Paper ballots are used in poorer and smaller counties.
- b) We can reject the hypothesis that a lower income increases the probability of using older machines (levers and punchcards) rather than newer machines (optical and electronic). If anything, there seem to be some evidence for the opposite correlation.<sup>13</sup>
- c) Analogously, one can reject that a larger percentage of minorities or seniors in the population is associated with a higher probability of using lever machines and/or punchcard machines.
- d) Higher population is associated with the use of older machines.

Does the lack of a negative correlation between income and older equipment mean that economic considerations are not relevant for the choice of voting equipment? Not at all. In the following section, we develop a simple model that can help shed some light on the relationship between income and voting equipment choice.

### **A Model of Voting Equipment Choice**

In this section we present a stylized model of voting equipment choice. To present the main insights in the simplest possible way, we assume only two periods and three types of equipment. Also, we will assume a deterministic environment. Extensions to allow for a larger (infinite) number of periods and a larger (infinite) number of equipment types, and extensions that allow for uncertainty are straightforward.

Table 2. Logit estimates

	(i)	(ii)
<i>(a) Paper</i>		
Median/income 1989	-.0258 (.0115)** [.0241]	-.0794 (.0169)** [.0383]**
Population 1990	-1.2 (.00844)*** [.0382]***	-.1035 (.00852)*** [.0369]***
% Age 65+		.0486416 (.0152558)*** [.0350578]
% Minority		-.0145374 (.0039053)*** [.0147063]
% Bachelors		.0752856 (.0148393)*** [.0332496]**
Local gov. Revenues/cap.		.0872 (.0352)*** [.0574]
<i>Log Likelihood</i>	-886.10886	-852.94436
<i>(b) Lever</i>		
Median income 1989	.00985 (.00710) [.0289]	.047 (.0109)*** [.0329]
Population 1990	.000199 (.000161) [.000321]	.000160 (.000.168) [.0369]
% Age 65+		-.0399883 (.0144685)*** [.0359365]
% Minority		.0134158 (.0029389)*** [.0102091]
% Bachelors		-.0569643 (.0118547)*** [.0192237]***
Local gov. revenues/cap.		-.3471

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Table 2. (Continued)

	(i)	(ii)
		(.0901)*** [.3726]
<i>Log Likelihood</i>	-1309.8533	-1268.0139
<i>(c) Punch</i>		
Median income 1989	.0444 (.00650)*** [.0157]***	.0475 (.01)*** [.0293]*
Population 1990	.000692 (.000215)*** [.000428]*	.00146 (.000265)*** [.000553]***
% Age 65+		-.0619581 (.0133427)*** [.0436589]
% Minority		-.0226474 (.0035292)*** [.0107334]**
% Bachelors		-.0423815 (.0101155)*** [.0241772]*
Local Gov. revenues/cap.		-1884 (.0713)*** [.1767]
<i>Log Likelihood</i>	-1488.3204	-1442.9768
<i>(d) Optical</i>		
Median income, 1989	.00618 (.00589) [.0183]	.00759 (.00858) [.0246]
Population 1990	-.00117 (.000301)*** [.000539]**	-.00187 (.000340)*** [.000664]***
% Age 65+		.0439749 (.0102525)*** [.0260792]*
% Minority		.014416 (.0023926)*** [.00701]**
% Bachelors		.0343289

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Table 2. (Continued)

	(i)	(ii)
		(.008214)*** [.0147417]**
Local Gov. revenues/cap.		.0845 (.0527) [.1285]
<i>Log Likelihood</i>	-2019.195	-1984.4268
Number of observations = 2999		
<i>(e) Electronic</i>		
Median income 1989	-.011 (.00972) [.0412]	-.0373 (.0136)*** [.0515]
Population 1990	.000240 (.000181) [.000184]	.000364 (.000189)** [.000293]
% Age 65+		-.1301422 (.0203253)*** [.0587795]**
% Minority		-.0073817 (.0039369)* [.0215262]
% Bachelors		.0043609 (.0131989) [.0235818]
Local Gov. revenues/cap.		-.9965 (.1578)*** [.3235]***
<i>Log Likelihood</i>	-885.44545	-827.82887
<i>(f) Lever/Punch</i>		
Median income, 1989	.0353 (.00604)*** [.0188]*	.0594 (.00895)*** .0246**
Population 1990	.00127 (.000279)*** [.000441]***	.00193 (.000309)*** [.000598]***
% Age 65+		-.0686848 (.0112502)*** [.0321606]**

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Table 2. (Continued)

	(i)	(ii)
% Minority		-.0051772 (.0025467)** [.0103535]
% Bachelors		-.0687412 (.0090527)*** [.0173012]***
Local Gov. revenues/cap.		-.3343 (.0633)*** [.1797]*
<i>Log Likelihood</i>	-1916.0679	-1843.9015
(g) <i>Lever/Punch (with paper counties dropped)</i>		
Median income 1989	.0225 (.00608)*** [.0181]	.043 (.00904)*** [.0251]*
Population 1990	.000966 (.000258)*** [.000399]**	.00159 (.000294)*** [.000553]***
% Age 65+		-.0493391 (.0117387)*** [.0328123]
% Minority		-.0077561 (.0026036)*** [.0099886]
% Bachelors		-.0578793 (.0090527)*** [.0160235]***
Local gov. revenues/cap.		-.1799 (.0626)*** [.1569]
<i>Log Likelihood</i>	-1739.6329	-1699.4657

All results with mixed counties dropped. Standard errors are reported in parenthesis beneath the coefficient estimates. Standard errors using Huber/White estimator of variance with clustering by state are reported in square brackets.

\*Denotes significance at the 10% level, \*\*denotes significance at the 5% level, and \*\*\*denotes significance at the 1% level of the coefficient using the estimator of variance denoted.

Median Income, Population, and Local Government Revenues per Capita in the 1000's. Number of observations = 2999.

Table 3. Multinomial logit estimates

	Lever	Electronic	Optical	Paper
Median Income 1989	.0016898 (.0134885) [.0416653]	-.071355 (.0160111)** [.0580642]	-.0328987 (.01143)** [.0282271]	-.108792 (.0192097)** [.0429349]**
Population 1990	-.0005234 (.0002662)** [.0006048]	-.0001427 (.0002649) [.0003752]	-.0028792 (.000391)** [.0007164]**	-.10104 (.0084515)** [.0362983]**
% Age 65+	.0143359 (.0185185) [.0546441]	-.073691 (.0234139)** [.0714956]	.0857917 (.0150121)** [.0412294]**	.093480 (.0194585)** [.0463201]**
% Minority	.0299783 (.0042573)** [.0132743]**	.0120657 (.0050199)** [.0234535]	.0279057 (.0038061)** [.0102305]**	.0075926 (.0050757) [.0179357]
% Bachelors	-.02031 (.0144546) [.0296048]	.0303002 (.0156993)** [.0285346]	.0590741 (.0112173)** [.0261835]**	.103665 (.0174836)** [.0424105]**
Local Gov. Revenues/cap.	-.1548112 (.1079107) [.4083854]	-.803326 (.1733754)** [.3623208]**	.3015399 (.0803753)** [.1916999]	.352951 (.0853416)** [.1947933]**

*Log Likelihood = -3877.3706*

All results with mixed counties dropped. Base group for comparison is punch card. Standard errors are reported in parenthesis beneath the coefficient estimates. Standard errors using Huber/White estimator of variance with clustering by state are reported in square brackets.

\*Denotes significance at the 10% level, \*\*denotes significance at the 5% level, and \*\*\*denotes significance at the 1% level of the coefficient using the estimator of variance denoted.

Median income, population, and local government revenues per capita in the 1000's. Number of observations = 2999.

In words, our model works as follows. Suppose that two counties – identical in everything except for income – are using technology A, when a better technology B becomes available.<sup>14</sup> Then, the richer county is more likely to adopt B, because its opportunity cost of adopting the innovation is lower (as long as utility is concave in income, the marginal benefits from alternative uses of income are lower in a richer counties). Now suppose that, after a while, a new technology C, better than B, becomes available. Which county will be more likely to adopt it? The richer county, which is now using B, or the poorer county, which is still using A? It depends. Although the opportunity cost of adopting C is lower in the richer county, the benefits from adopting C are also lower. By assumption, switching from B to C will not give as high a gain as the more dramatic switch from A to C. In other words, the net benefits from adopting the new technology C depend on a county's current technology. All other things equal, the less advanced is the county's current technology, the higher are the benefits from switching to the most advanced technology C.

Table 4. Multinomial logit estimates: punch lever aggregate

	Electronic	Optical	Paper
Median income 1989	-.0709019 (.0148925)*** [.0524239]	-.03318 (.0098188)*** [.0261779]	-.1087107 (.0182841)*** [.041473]***
Population 1990	.0000534 (.0002356) [.0003443]	-.0025936 (.0003745)*** [.0007664]***	-.1006475 (.0084507)*** [.0362795]***
% Age 65+	-.0797589 (.0219173)*** [.0588864]	.0791193 (.012535)*** [.0308081]***	.0871535 (.0176673)*** [.0402802]**
% Minority	-.0040822 (.0042822) [.021863]	.0115665 (.0027643)*** [.0096826]	-.0087151 (.0043471)** [.0402802]
% Bachelors	.0391928 (.0146099)*** [.0245616]	.0674331 (.0097107)*** [.0186062]***	.1117743 (.0165751)*** [.0371306]***
Local gov. revenues/cap.	-.7345114 (.1672639)*** [.3274512]**	.3680136 (.0691487)*** [.1861445]**	.4192669 (.074916)*** [.1898538]**

All results with mixed counties dropped. Base group for comparison is punch card/lever. Standard errors are reported in parenthesis beneath the coefficient estimates. Standard errors using Huber/White estimator of variance with clustering by state are reported in square brackets. \*denotes significance at the 10% level, \*\*denotes significance at the 5% level, and \*\*\*denotes significance at the 1% level of the coefficient using the estimator of variance denoted.

Median income, Population, and Local government revenues per capita in the 1000's. Number of observations = 2999

If the difference between “benefit effect” (larger in poorer county) and “cost effect” (larger in richer counties) is high enough, we may see a large number of richer counties “leapfrogged” by relatively poorer counties.<sup>15</sup> Nonetheless, our framework implies that, when controlling for past income levels, a higher income today is associated with a lower probability of using older equipment.

More formally, consider a two-period model. In each period, counties can use “type 0” equipment (paper ballots) at no cost. In period 1, a county can adopt “type 1” equipment (“old machines”). In period 2, a county can adopt “type 2” equipment (“new machines”). The quality of period  $t$  equipment is denoted by  $x_t$  (with  $x_2 > x_1 > x_0$ , where  $x_0$  is the quality of paper ballots). The utility of county  $i$ 's decision-maker in period  $t$  is given by

$$U_t^i = S(q_t^i) + V(y_t^i - c_t^i) \quad (1)$$

where  $q_t^i$  denotes the quality of voting machines in county  $i$  at time  $t$ ,  $y_t^i$  is county  $i$ 's income per capita at time  $t$ , and  $c_t^i$  denotes voting equipment costs per capita at time  $t$ .  $S(q_t^i)$  is the utility from voting equipment, and is increasing in  $q_t^i$ .  $V(y_t^i - c_t^i)$  is the utility from "consumption" (i.e., from all other uses of income, other than purchasing voting equipment), and is increasing and concave in  $y_t^i - c_t^i$ . If at time  $t$  the county adopts machines of type  $t$  we have  $q_t^i = x_t$  and  $c_t^i = k_t$  where  $k_t$  is the cost of type- $t$  machines.<sup>16</sup> Otherwise,  $q_t^i = q_{t-1}^i$  and  $c_t^i = 0$ .<sup>17</sup>

Implicit assumptions in our model are that:

- a) Voting machines do not depreciate from one period to the next. This is a good approximation of reality. Actual machines are very durable, especially because they are used less than a few days a year.
- b) Voting machines cannot be resold in a secondary market. This is also consistent with reality – the only major exception being the recent move by Palm Beach County to sell its infamous punchcard machines on eBay to finance a state-mandated overhaul of its voting equipment.

It is important to notice that the costs of changing equipment type do not need to be viewed exclusively as physical costs associated with buying new machines. In fact, a large component of those costs may well stem from other "adjustment costs," such as the physical and psychological costs associated with modifying existing practices and procedures, the political costs due to the disruption of existing 'rents' associated with the use of the old machines (say, end of existing maintenance and storage contracts), etc. In other words, shifting from a *type* of equipment to a different *type* of equipment (rather than replacing older machines with "newer" machines of the same old type) may entail additional economic and political costs, over and above the costs of purchasing new machines. In our simple model we abstract from such additional economic and political costs. If we were to allow for them, our conclusions would be strengthened.<sup>18</sup>

County  $i$ 's decision maker maximizes

$$U_1^i(q_1^i, y_1^i - c_1^i) + \beta U_2^i(q_2^i, y_2^i - c_2^i), \quad (2)$$

where  $0 \leq \beta \leq 1$  is the subjective discount factor.

A brief discussion of the objective function is in order. Our interpretation is that, historically, decisions have been taken by local officials who have maximized their own utility function. What objectives have been pursued by such agents? Certainly not maximization of accuracy. Although expert evaluations of the relative performance of different voting equipment have focused mainly on "reliability" (minimization of "residual votes," spoiled ballots, etc.), it seems unlikely that, before the Florida crisis, accuracy played a paramount

role in actual decisions over voting machinery.<sup>19</sup> If “reliability” had been the key goal of local officials, one would be hard pressed to explain why they bothered to adopt newer machines at all, when paper ballots seem to provide the most reliable, accurate system available (Ansolabehere et al., 2001). Either local officials were systematically mistaken on the characteristics of the machines they adopted, or they were willing to trade off reliability with other benefits from more advanced machines.<sup>20</sup>

In particular, voting machines are labor-saving devices: They make voting procedures (especially vote-counting) quicker and easier. And the labor saved tends to belong to county officials themselves and their assistants.<sup>21</sup> When priority is given to the speed and convenience of vote counting, mechanized lever machines can be viewed as “progress” with respect to paper ballots, computerized punchcard machines as “progress” with respect to lever systems, etc.<sup>22</sup> More generally, one can assume that innovation in the voting equipment industry is targeted to the satisfaction of its costumers (the county officials), and that, on average, successful (i.e., adopted) innovations must have provided higher utility to such customers.<sup>23</sup> All things considered, it seems reasonable to assume that, from the perspective of local officials, newer voting equipment has been perceived as “better” equipment.<sup>24</sup>

In this section we will solve our model for the case  $\beta = 0$ .<sup>25</sup>

Since  $S(\cdot)$  is increasing and  $V(\cdot)$  is increasing and concave, it is immediate to obtain the following:

*Proposition 1. In period 1, a county  $i$  will adopt voting machines of type 1 if and only if its income is higher than  $y_1^*$ , which is implicitly defined by the following equation:*

$$S(x_1) + V(y_1^* - k_1) = S(x_0) + V(y_1^*) \quad (3)$$

That is, the richer counties in period 1 will adopt type-1 machineries, whereas the poorer counties will not.

For example, if  $V(\cdot) = \ln(\cdot)$ , we have

$$y_1^* = \frac{k_1 e^{S(x_1) - S(x_0)}}{e^{S(x_1) - S(x_0)} - 1}$$

Since  $S(\cdot)$  is increasing, the benefits from adopting type-2 technology, *ceteris paribus*, are higher for those counties that have not adopted type-1 technology in period 1. Therefore, we have:

*proposition 2. In period 2, a county with  $q_1^i = x_0$  will adopt machines of type 2 if and only if its income is above  $y_2^*$ , which is implicitly defined by the*

following equation:

$$S(x_2) + V(y_2^* - k_2) = S(x_0) + V(y_2^*) \tag{4}$$

whereas a county with  $q_1^i = x_1$  will adopt machines of type 2 if and only if its income is above  $y_2^{**}$ , which is implicitly defined by the following equation:

$$S(x_2) + V(y_2^{**} - k_2) = S(x_1) + V(y_2^{**}) \tag{5}$$

It is immediate to verify that  $y_2^{**} > y_2^*$ .  
 For example, if  $V(\cdot) = \ln(\cdot)$ , we have

$$y_2^{**} = \frac{k_2 e^{S(x_2) - S(x_1)}}{e^{S(x_2) - S(x_1)} - 1} > y_2^* = \frac{k_2 e^{S(x_2) - S(x_0)}}{e^{S(x_2) - S(x_0)} - 1} \tag{6}$$

As shown in Figure 1, when income is correlated across the two periods, a high enough gap between  $y_2^{**}$  and  $y_2^*$  and a high enough correlation between first-period income and second-period income is consistent with a positive correlation between second-period income and use of type-1 equipment in period 2. However, it is immediate to obtain the following.

*Corollary. A positive correlation between second-period income and use of type-1 equipment in period 2 vanishes when conditioning on past income.*

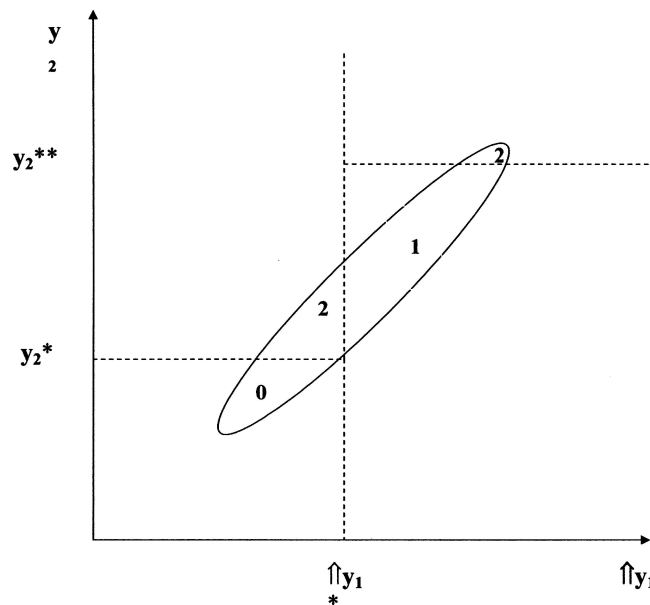


Figure 1.

*Specifically, when we look at conditional distributions – that is, at counties with the same income in period 1 – we have that the use of older equipment is either independent of period-2 income (for  $y_2^{**}$  large) or negatively associated with period-2 income (for  $y_2^{**}$  small).*

In the following section we will use our simple model’s insights to investigate the relationship between present and past income and voting equipment usage.

### **History Matters: The Role of Past Income**

In this section we will investigate whether the empirical evidence is consistent with our hypothesis that the current distribution of voting equipment use is the outcome of historical decisions.

Ideally, we would like to have historical data on voting equipment use of individual counties over the past few decades. Because we do not have such panel data, we first consider aggregate data about the distribution of voting equipment in the 1980 and 2000 elections, as provided in Ansolabehere et al. (2001). As shown in Table 5, we find that between 1980 and 2000 the share of counties that used optical or electronic machines went from 1% to 49.1%. The transition took place through reductions in the number of counties that used paper ballots (from 40.4% to 12.5%) or lever machines (from 36.4% to 14.7%). By contrast, the share of counties that used punchcard machines barely moved (19.1 vs. 19.2). This pattern is consistent with our story.

To provide a more direct and formal test of our hypothesis, we calculate logit estimates using past values for income. The results are reported in Tables 9a–9b, and provide strong support for our model. In Table 9 we aggregate lever and punchcard (as our “type-1 technology”) and obtain the following results:

*Table 5.* Usage of voting equipment in the 1980 and 2000 elections

	% Counties 1980	% Counties 2000
Paper	40.4	12.5
Lever	36.4	14.7
Punch	19.1	19.2
Optical	0.8	40.2
Electronic	0.2	8.9
Mixed	3.0	4.4

*Source:* “A Preliminary Assessment of the Reliability of Existing Voting Equipment,” The Caltech/MIT Voting Project, Version 1: February 1, 2001.

Table 6. Averages – Historical population and median family income

	All	Lever	Punch	Elect	Optical	Paper	Lev./Pun.	Elc./Opt.
MInc89	28142	28817	30574	27918	27792	24799	29814	27814
MInc79	27888	27332	30580	27517	27830	24824	29173	27774
MInc69	23322	23004	26314	22690	22770	21138	24884	22756
MInc59	16243	15361	18793	15363	15770	15317	17316	15698
Pop90	76166	96615	139259	92282	54584	8869	120806	61314
Pop80	69104	94366	121996	85300	48533	8948	110029	55076
Pop70	61636	94153	104961	75128	41501	8193	100291	47490
Pop60	54406	87565	87694	66246	37112	8591	87639	42304
Pop50	45829	79208	67676	53893	32182	9263	72624	36053
Pop40	40118	72850	54925	45618	28805	9969	62605	31805
Pop30	37380	69062	49749	41219	27081	10216	58023	29604

Note: Mixed Counties, the District of Columbia, Alaska and Hawaii dropped from the sample.

Table 7. Correlation matrix, median family income 1989, 1979, 1969, 1959

	Income 1989	Income 1979	Income 1969	Income 1959
Income 1989	1			
Income 1979	0.87913	1		
Income 1969	0.848535	0.89219	1	
Income 1959	0.694591	0.775071	0.882233	1

Table 8. Correlation matrix, population 1990–1930

	P 1990	P 1980	P 1970	P 1960	P 1950	P 1940	P 1930
P 1990	1						
P 1980	0.99231	1					
P 1970	0.96842	0.98996	1				
P 1960	0.93652	0.96769	0.99211	1			
P 1950	0.86569	0.91033	0.95343	0.98112	1		
P 1940	0.79904	0.85327	0.90777	0.94639	0.98941	1	
P 1930	0.76071	0.81963	0.87898	0.92238	0.97626	0.99655	1

1. Income in 1969 has a positive effect on the probability of using lever or punchcard machines in 1999. Such effect is larger than the effect of 1989 income in our previous logit estimation (Table 2f), when we did not control for 1969 income.
2. When income in 1969 is included in the regression, the effect of 1989 becomes insignificant.

Table 9. Historical income logit estimates

	(i)	(ii)
<i>(a) Lever/Punch</i>		
Median income 1969	.0578 (.0126)*** [.0465]	.091 (.014)*** [.0368]***
Median income, 1989	.00528 (.0105) [.0257]	.0197 (.0124) [.027]
Population 1990	.000942 (.000269)*** [.000436]**	.00136 (.000310)*** [.000605]**
% Age 65+		-.0677762 (.011929)*** [.0324112]**
% Minority		.0021351 (.002754) [.0103593]
% Bachelors		-.0788039 (.0093558)*** [.0169909]***
Local gov. revenues/cap.		-.4337 (.0746)*** [.2167]**
<i>Log Likelihood</i>	-1879.9487	-1793.974
<i>(b) Punch</i>		
Median income 1969	.1732 (.0161)*** [.0396]***	.193 (.0175)*** [.0408]***
Median income 1989	-.0599 (.0126)*** [.0264]**	-.0569 (.015)*** [.0267]**
Population 1990	.000262 (.000183) [.000328]	.000760 (.000258)*** [.000480]
% Age 65+		-.0591836 (.0147482)*** [.0490966]

(Continued on next page)

Table 9. (Continued)

	(i)	(ii)
% Minority		-.0122754 (.0037583)*** [.0099833]
% Bachelors		-.0536086 (.01071)*** [.0233077]**
Local gov. revenues/cap.		-.4545 (.097)*** [.2718]*
<i>Log Likelihood</i>	-1407.5589	-1360.5877

All results with mixed counties dropped. Standard errors are reported in parenthesis beneath the coefficient estimates. Standard errors using Huber/White estimator of variance with clustering by state are reported in square brackets.

\*Denotes significance at the 10% level, \*\*denotes significance at the 5% level, and \*\*\* denotes significance at the 1% level of the coefficient using the estimator of variance denoted.

Median income, population, and Local government revenues per capita in the 1000's. Number of observations = 2962.

When we consider the probability of using punchcard machines alone (Table 8b) we obtain even stronger results, as one may expect from the fact that 1969 income is within the time frame in which punchcard machines were adopted, whereas lever machines were adopted in many counties before the Second World War.<sup>26</sup> In particular, we have

1. Income in 1969 has a positive effect on the probability of using punchcards in 1999. In fact, such effect is one order of magnitude larger than the effect of 1989 income in our previous logit estimation (Table 2c).
2. When income in 1969 is included in the regression, the effect of income in 1989 becomes *negative*.

In other words, the positive correlation between most recent income and use of punchcards is completely due to the positive correlation between most recent income and past income (i.e., the county's income when punchcards were actually adopted). When past income is explicitly taken into account, the effect of current income – as expected in our model – becomes negative.

By taking explicitly into account the role of historical income, we can provide a factually consistent story about the relationship between income and the use of different voting equipment. Our story provides a solution for the “paradox of chads”: “chads” are not found among poorer counties but among

Table 10. Historical population logit estimates

	(i)	(ii)
<i>(a) Lever</i>		
Population 1930	.00433 (.00101)*** [.00218]**	.00507 (.00107)*** [.00209]**
Population 1990	-.00174 (.000652)*** [.00106]*	-.00215 (.000735)*** [.00128]*
Median income 1989	.0161 (.00854)** [.0334]	.0579 (.0122)*** [.0359]*
% Age 65+		-.0619088 (.0161329)*** [.0354578]*
% Minority		.0151031 (.0032171)*** [.0116579]
% Bachelors		-.0665901 (.0128679)*** [.0203334]***
Local gov. revenues/cap.		-.3978 (.0985)*** [.3725]
<i>Log Likelihood</i>	-1263.0142	-1208.7098
<i>(b) Punch</i>		
Population 1930	-.00180 (.000822)** [.00146]	-.00247 (.000930)*** [.00133]*
Population 1970	.000938 (.000478)** [.000802]	.00175 (.000603)*** [.000884]**
Median income 1969	.1774 (.0162)*** [.0393]***	.1982 (.0178)*** [.0399]***
Median income 1989	-.0604 (.0128)*** [.0267]**	-.0581 (.0151)*** [.0274]**
% Age 65+		.0517037 (.0148848)*** [.0490287]

(Continued on next page)

Table 10. (Continued)

	(i)	(ii)
% Minority		-.0105686 (.0037785)*** [.0101945]
% Bachelors		-.0515015 (.0108287)*** [.02371]**
Local gov. revenues/cap.		-.4759 (.0987)*** [.2789]*
<i>Log Likelihood</i>	-1394.5174	-1352.0327

All results with mixed counties dropped. Standard errors are reported in parenthesis beneath the coefficient estimates. Standard errors using Huber/White estimator of variance with clustering by state are reported in square brackets.

\*Denotes significance at the 10% level, \*\*denotes significance at the 5% level, and \*\*\* denotes significance at the 1% level of the coefficient using the estimator of variance denoted.

Median income, Population, and Local government revenues per capita in the 1000's. Number of observations = 2946.

counties that used to be richer in 1969 – and, therefore, are still likely to be relatively richer in the 1980s and 1990s. But when past income is controlled for, a “nonparadoxical” negative relationship between present income and use of older punchcard equipment emerges.

### History Matters: The Role of Past Population Size

Income per capita is an important determinant of voting equipment use. But it is not the only determinant. In this section the analysis is extended to include another key variable: population size. We argue that, all other things equal, a larger population increases the probability of adopting more advanced voting technology. The aggregate cost of adopting a new technology includes an important fixed component, which is independent of size. These fixed costs stem from numerous sources, including the indivisibility of machines and the existence of large fixed costs in initial training and “adaptation.”<sup>27</sup> Henceforth, cost per capita is decreasing in the size of a county.<sup>28</sup> Formally, we can expand the model in Section 3 by assuming that the costs per capita of adopting technology of type  $t$  in a county with population equal to  $N_t$  are given by

$$k_t + \frac{f_t}{N_t} \quad (7)$$

where  $f_i$  is a fixed cost. Moreover, benefits from adopting more advanced technology may be positively related to total size (for example, the benefits from speed in vote-tallying may be higher in larger counties). Hence, our previous specification can be extended to include population as an argument in the  $S(\cdot)$  function, e.g.,

$$S(q_i N_i) \tag{8}$$

Does our extension to population size imply that *currently* larger counties – controlling for income – will be more likely to use more advanced technology? No, for the same reasons why a *currently* higher income does not guarantee a better technology. What matters is population size *when* the different types of equipment were introduced. Since we have data for population before the Second World War, we can disaggregate lever machines and punchcard machines, and test whether their use today is related to past values of population as predicted by our model. Tables 10a–10b show logit estimates when *past* values of population are included as explanatory variables. The results confirm our general message. As predicted by our model, the probability of using lever machines in 1999 is *positively* related to population in 1930, but *negatively* related to population in 1990. Controlling for today’s population size, countries that were larger in 1930, when lever machines were state-of-the-art, were more likely to have adopted them. But, *controlling* for 1930 size, a larger size in 1990 means a higher chance of having replaced lever machines with more updated equipment by 1999. By the same token, the probability of using punchcard machines is *negatively* related to population in 1930, but *positively* related to population in 1970.

The extension of the model to include population size adds realism and explanatory power to our basic framework without changing the central insights. For example, the role of population size can also help explain an additional fact, documented in Ansolabehere et al. (2001): Counties that abandoned paper ballots were more likely to adopt optical scanners, whereas counties that abandoned lever machines were more likely to adopt electronic machines. Electronic machines have much higher fixed costs than optical scanners (which, by contrast, have higher variable costs because they require expensive special paper). Hence, we should expect that counties with larger population would adopt electronic machines rather than optical scanners. Because larger counties are also more likely to have used lever machines rather than paper ballots in the past, a pattern lever to electronic/paper to optical is soon established.<sup>29</sup>

Another possible extension of our basic framework entails an explicit role for human capital. The introduction of newer technology, other things being equal, is likely to bring about higher benefits and smaller costs (from learning etc.) when voters and officials have higher education. Because these effects are probably higher for the computerized technologies of the 1980s and 1990s

(optical scanners and electronic machines), it is not surprising that the percentage of population with a college degree is positively related with the adoption of such equipment. The analysis of historical levels of human capital in the adoption of older technology is left for further research.

Other extensions could focus on the role of local public finance across different jurisdictions. In our specification we simply assume that the relevant decision maker obtains utility from the county (average or median) “income.” In reality, the relationship between a county’s income and the resources available to local officials is also mediated by institutional mechanisms and constraints that may differ across jurisdictions. At the empirical level, they are partly captured by the independent effect of current local government revenues per capita in our regressions. The analysis of the effects of these variables from a historical perspective is also matter for future inquiry.

### Concluding Remarks

In this paper we have documented the relationship between usage of different types of voting equipment and county characteristics. In contrast to widespread belief, machines of older types are not used in relatively poorer counties. We have provided a stylized model in which the adoption of new voting equipment depends on a county’s income, population, and existing type of equipment at the time the new technology is introduced. We have successfully tested numerous implications of our model. In particular, as predicted by our theory, when we control for the relevant decision variables (income and population size) at the time in which the older technologies were state-of-the-art, the effects of more recent income and population become negative or insignificant.

Overall, we have found evidence that voting equipment adoption in the United States has been characterized by significant “leapfrogging,” with the latest technology being adopted by counties that had not adopted the previous state-of-the-art equipment. Our bottom line is that history matters: The current distribution of voting equipment reflects political decisions taken over several decades. Failing to take into account the dynamic aspects of the process can lead to a distorted view of the phenomenon.

Specifically, our analysis helps clarify the relationship between economic and demographic factors and the adoption of different voting equipment. We have documented how “worst equipment” is *not* concentrated in poorer counties. However, such finding does *not* imply that economic factors played no role in determining the distribution of current voting equipment. In contrast, we have emphasized how such distribution is significantly affected by current and past economic and demographic factors. In particular, our analysis implies that, *given current equipment*, higher income is indeed associated with a *higher* probability of updating one’s technology.

These findings shed new light on the debate over the causes and consequences of voting equipment choice in the United States and correct some misconceptions that have colored such discussions. In particular, our findings seem especially relevant with respect to the current political debate over the allocation of federal funds targeted to the upgrade of voting equipment.

Finally, we think that our study provides valuable insights on the more general issue of the adoption of new technology by decentralized public authorities. We suspect that similar mechanisms and outcomes are at work with respect to other decisions involving the upgrade of durable public goods across different jurisdictions, and that our analysis can shed some light on the political economy of this larger class of political decisions.

## Notes

1. For an explanation of this terminology, see section on “Types of voting equipment in the United States.”
2. The Washington Post (2002).
3. The remaining 4.5% of counties, containing 9.1% of registered voters, used “mixed systems” (i.e., two or more types of equipment).
4. Our main source for historical information is the Federal Election Commission ([www.fec.gov/elections.html](http://www.fec.gov/elections.html)).
5. Heterogeneity is only minimally reduced within states. In Pennsylvania, Virginia and several other states *each* type of available equipment is used by one or more counties.
6. Mixed systems are mainly found in those states, such as Massachusetts and Michigan, in which decisions over vote equipment are not taken by counties but by towns.
7. The historical information in this section has been obtained from the Federal Election Commission ([www.fec.gov/elections.html](http://www.fec.gov/elections.html)).
8. Imperfectly punched chads include “hanging chads” (one corner of the chad is hanging on the punchcard), “swinging chads” (two corners are attached to the card), and “pregnant chads” (a hole is punched through a fully attached chad).
9. Votomatic systems were used by 18.4% of the counties in 1999. Datavote systems were used by 1.8% of counties. Since the two systems are basically identical, we aggregate them as “punchcard systems.” Our results would not change if we were to consider them as separate systems.
10. A related controversy has involved the different consequences of precinct counting versus central counting of optically scanned ballots (e.g., see Commission on Civil Rights, 2001). Our data does not contain details on different uses of machines of the same type.
11. We also performed estimations with additional variables (population density and percentage of votes for the Democratic candidate in presidential elections). The variables turned out insignificant and did not change the results.
12. We have also performed logit estimates with state dummy variables, to control for state effects. The introduction of such dummies does not change the overall results.
13. This result should not be confused with the prediction that, should one run an “ordered” logit regression, “newer” machines would not be correlated with “higher” income. Because poorer counties *do* use older voting systems (paper), forcing a monotonic relationship on the data may in some cases generate positive estimates for the income effect. However, those estimates do not capture the “nonmonotonicity” in the relationship, which clearly emerges from our unconstrained multinomial logit estimates. In other words, our key

- finding is that in the data higher income is NOT associated with “newer” equipment, but with “intermediate,” “middle-age” equipment, such as punchcard machines.
14. As discussed below, terms such as “better,” “costs,” and “benefits” refer to the objective function of the relevant decision-maker, the county’s local official. More idealistically, one may interpret the utility of the county as equal to the utility of the county’s median voter or representative citizen.
  15. The possibility of leapfrogging in the adoption of innovation is familiar to students of industrial organization, economic development, and international economics. For example, see Aghion and Howitt (2000) and Brezis et al. (1993).
  16. For simplicity, we assume that the costs of adopting type- $t$  equipment are the same for all counties. The model can be easily extended to allow for different costs per capita across counties of different size. We will return to this extension later.
  17. We abstract from “running costs,” which could be easily added without much gain of insights.
  18. Moreover, if some depreciation of equipment were to take place over time, the existence of additional economic and political costs associated with changing *type* of equipment could help explaining why some counties may decide to replace their machines with *new* machines of the *old* type rather than with *new* machines of the *new* type (a phenomenon that took place in a few counties historically). This effect would also strengthen our conclusions.
  19. “Reliability” as low “residual vote” should not be confused with the minimization of actual machine failures, which may well be a high priority for local officials. In fact, state and federal voting equipment certifications impose tight standards for machine failure rates. As pointed out by Ansolabehere et al. (2001), human factor (interaction of voter and machine) rather than pure mechanical failure seems to drive much of “error” in voting.
  20. A third possibility is that current analyses of voting equipment reliability do not provide correct estimates of relative accuracy.
  21. Voters may also benefit from shorter lines if voting procedures are speeded up by the machines.
  22. Historically, the shift from paper ballots to lever machines might also have been motivated as an attempt by higher officials to reduce voting fraud.
  23. An explicit analysis of the supply side of the voting equipment industry is beyond the scope of this paper.
  24. Other hypotheses about the decision-makers’ objective functions should also be mentioned. For example, we abstract from the effects that voting equipment choice could have on the electoral outcomes. The perspective of undercounting, vote counting manipulations, and even frauds may have played a role in the process of voting equipment selection. For instance, different voting technologies may have been associated with different scope for controlling the vote counting process by incumbents and their associates. A second set of factors has to do with the interactions – including lobbying, campaign contributions, etc. – between decision-makers and equipment producers. Such political mechanisms, which we do not pursue in this paper, could provide alternative explanations for voting equipment choice over time.
  25.  $\beta = 0$  is a realistic assumption for our model: Voting equipment is chosen by local officials with horizons that are unlikely to exceed their terms in office, whereas we have seen, the introduction of new types of voting equipment has taken place over long intervals. The straightforward generalization for  $0 < \beta \leq 0$  is available on request. Not surprisingly, the main effect of a nonzero  $\beta$  is to increase the fraction of counties that switch to type-1 machines in period 1.
  26. Similar but slightly less strong results are obtained using 1959 income.

27. See Office of Federal Elections and National Bureau of Standards (1975).
28. This can be viewed as an application of the standard idea that the per capita cost of public goods should be decreasing in size. For a discussion of this issue, see for example Alesina and Spolaore (2003).
29. Of course, factors such as habits and learning may also have played an important role (electronic machines are conceptually similar to lever machines, whereas optical scanners use a “paper” technology).

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