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Who are the internet voters? An age, period and cohort analysis of e-voting use

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ABSTRACT

Existing research highlights age-related differences in internet voting but fails to disentangle the underlying effects. We conduct an age, period and cohort (APC) analysis of e-voting use on a unique set of registered, panel data covering 46 ballots in Switzerland between 2004 and 2019. Our findings reveal a joint influence of cohort and age effects on the likelihood of voting online. Voters born between the mid-1960s and mid-1980s display the highest e-voting rates, surpassing both younger and older cohorts. However, within these intermediate cohorts, e-voting usage declines notably with age. In contrast, age exerts little to no influence on e-voting among the youngest cohort (born in the 1990s) and the oldest cohorts (1930s and 1940s), with usage nearing zero for the latter group. These results refine our understanding of how age influences e-voting adoption and help to evaluate its potential to increase voter turnout.

1. Introduction

Internet voting[1] increases convenience and reduces the cost of voting to a minimum. The introduction of internet voting was therefore expected to increase voter turnout or, at least, to stem the decline in turnout in Western democracies (Alvarez et al., 2009; Norris, 2005, Trechsel et al., 2007). In particular, internet voting should help to reach young citizens, who are underrepresented among voters but have a higher affinity for the internet than older citizens. On the one hand, studies examining the use of internet voting have indeed found that e-voting is particularly attractive to young and middle-aged citizens (Serdült et al., 2015). On the other hand, however, internet voting has not lived up to its promise of addressing low voter turnout among young people. The few studies that have examined whether internet voting promotes participation among young voters either find no effect (Germann and Serdült, 2017) or reverse effects, namely that e-voting has positive impact on old voters, but (much) less so on young voters (Ciancio and Kämpfen, 2023; Petitpas et al., 2021).

The bottleneck model proposed by Vassil and Weber (2011) helps to explain the apparent paradox existing between the intensive use of e-voting by young voters and the lack of measurable impact on their participation[2]: While the mobilization potential of e-voting is greatest among peripheral voters, such as young people, these are precisely the people who are least likely to vote in the first place. Among them, the use of e-voting may thus not be associated with a higher propensity to participate. This highlights the need to distinguish between the use of internet voting and its impact on voter turnout, and invites us to analyze the use of e-voting in more detail.

However, assessing how e-voting use varies with age raises an additional and perhaps more problematic issue, that of identifying the effects at work. Are age differences in e-voting use due to an ageing effect, a cohort effect – or a combination of the two? So far, existing studies have failed to identify the specific effect at work. This failure may lead to inaccurate results about how voter turnout varies across

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[1] Internet voting is a specific form of e-voting that grants citizens the possibility to cast their vote through the Internet. In this paper, we use internet voting, i-voting, online voting and e-voting interchangeably, bearing in mind that by e-voting we mean *remote e-voting* and not on-site electronic voting (at the polling station).

[2] The bottleneck metaphor was first coined by Lazarsfeld et al., 1948 to highlight that voters who are more attentive to politics also have more stable preferences, whereas potential vote switchers are far less attentive to it and, therefore, less exposed to information that might lead them to change their mind. As a result of the "bottleneck of conversion" (Lazarsfeld et al., 1948: 95), the high potential for vote change among unengaged citizens is not realized due to their low media exposure. A similar argument is crux in Zaller's (1992) axiom of resistance: more aware citizens are more likely to resist the political messages they receive if these messages do not conform to their political predispositions.

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ages.

Against this background, the purpose of this paper is to conduct an age, period and cohort analysis of e-voting use. To do so, one needs data that provide information on citizens' use of e-voting for a long time-span. Our dataset meets these requirements. It provides official, registered data on citizens' participation (as opposed to abstention) and related voting mode covering 46 ballots (national and regional direct democratic votes and elections) held between 2004 and 2019 in the canton of Geneva, Switzerland. Together with Estonia, Switzerland is a pioneer in internet voting, and within Switzerland, Geneva is the canton with the most extensive internet voting experience. In addition to information on participation and voting channel, our dataset includes a handful of socio-demographic variables: gender, age, marital status, residence duration, citizenship status, and place of residence (municipality). More importantly, it includes a numerical code that allows us to track an individual's participation and use of e-voting across ballots.

Methodologically, we rely on an age, period and cohort (APC) analysis of repeated, panel data. Since the data follow individuals over time, observations are cross-classified into individuals and ballots. This modelling strategy helps to address the identification problem inherent in the analysis of APC effects (Bell, 2020; Bell and Jones, 2015, 2021).

The next section presents the analytical framework. It starts with a review of the literature of e-voting use and e-voting effects, with a focus on studies addressing the related role of age. We then specify the respective roles that age, cohort and period effects may play for e-voting use, and from this we derive a set of hypotheses. In the methodology section, we discuss how we address the APC identification problem and present our resulting modelling strategy. This sets the stage for the empirical analysis. The concluding section puts the results in perspective and highlights their broader implications.

2. Analytical framework

An important stream of the e-voting literature has attempted to assess whether this new voting channel has had a measurable effect on overall voter turnout. The answer tends to be negative. Studies in different countries (Canada, Estonia, Switzerland, UK, US) and at different levels of government find no or only very weak effects of offering e-voting on aggregate turnout (e.g. Germann and Serdült, 2017; Oostveen and Van den Besselaar, 2004; Solvak and Vassil, 2016). A notable exception is Goodman (2014) study of local elections in Ontario, Canada, which shows that e-voting had a significant effect on electoral participation, especially in municipalities where vote by mail was not offered in parallel. The latter finding points to the importance of the context in which e-voting is offered. If another convenient voting channel such as postal voting is already in place, as it is the case in Switzerland, internet voting tends to replace the existing voting mode rather than attract new voters (Germann and Serdült, 2017; Solvak and Vassil, 2016).[3]

Analyses of the impact of internet voting on mobilizing specific groups of voters are more positive. In both Estonia and Switzerland, offering e-voting increases turnout among peripheral voters, i.e. among individuals who usually abstain or vote only occasionally (Petitpas et al., 2021; Solvak and Vassil, 2016). Again, however, the results are not entirely clear-cut, especially with respect to age effects. In Switzerland, Germann and Serdült (2017) find no difference between young and old voters. In contrast, in Petitpas et al.'s (2021) study, offering e-voting increases participation among voters aged 60 to 80, but has a smaller effect on participation among those under 30. Finally, Ciancio and Kämpfen (2023) find that internet voting has positive effects of individuals aged 80 and more.

Differences between the three studies in terms of level of analysis, estimation methods and causal identification assumptions may explain these different results. For its part, the "bottleneck" model developed by Vassil and Weber (2011) helps to explain why the mobilization effects of e-voting on some specific segments of citizens, such as young voters, may remain unnoticed on the aggregate level. The bottleneck effect arises from two countervailing tendencies. On the one hand, e-voting is most likely to be used by people who are regular voters, and who resort to another mode of voting if e-voting is not available. On the other hand, turnout can only increase if irregular voters mobilize and vote – via the internet. But precisely because irregular citizens do not vote or vote infrequently, their use of e-voting can hardly affect the aggregate turnout: "if a large share of citizens simply switches from paper voting to e-voting, while the non-participating minority does not start to participate in elections as a result of the new mode, then widespread usage of e-voting has negligible effects on voter turnout" (Solvak, 2016: 93). Empirically, while positive turnout effects on specific subgroups should still be visible in aggregate turnout, these effects are difficult to detect due to low statistical power.

The bottleneck model reminds us that usage does not equal impact and invites us to take a closer look at the use of e-voting. If e-voting is able to reach citizens who are least likely to participate, such as young voters, this possible limited mobilization effect is already an achievement, even if it does not show up at the aggregate level.

Finally, it should be added that e-voting is especially attractive to a segment of citizens not covered by the present study, namely citizens residing abroad. For them, internet voting saves the return time associated with postal service, and thus makes sure that their vote is correctly recorded. Existing studies demonstrate that offering e-voting has positive turnout effects among expatriates – effects that are greater than among residents (e.g. Germann and Serdült, 2014, Germann, 2021). Not surprisingly then, expatriates, have become the main focus of internet voting programs in countries like France or Switzerland.

2.1. *Age and e-voting use*

A meta-analysis of 22 empirical studies conducted in different countries, including six in Switzerland, shows that *age* is *the* most important socio-demographic determinant of e-voting use (e.g. Serdült et al., 2015). It has a significant impact in 21 out of the 22 studies reviewed, and in most cases young voters use internet voting far more frequently than old voters. This is the case in Estonia (Breuer and Trechsel, 2006; Trechsel et al., 2007; Alvarez et al., 2009) in the U.S. (Solop, 2001), in Canada (Delvinia Report, 2004, 2007, Goodman, 2014), in Norway (Segaard et al., 2014), in Switzerland (Sciarini et al., 2013; Serdült and Trechsel, 2006) or in the UK (Henry, 2003). However, the evolution of e-voting use across age is not monotonic, but curvilinear (Serdült et al., 2015): In most studies, it is not the youngest who use e-voting most, but the second age group of middle-aged voters between 30 and 40 or 50.

The greater use of internet voting among young citizens holds up well to more sophisticated tests based on multiple regressions that additionally include other socio-demographic variables, such as marital status or education (e.g. Alvarez and Nagler, 2000; Breuer and Trechsel, 2006; Trechsel et al., 2007; Trechsel and Vassil, 2011; Sciarini et al., 2013). In contrast, the influence of age on e-voting use becomes insignificant when attitudinal variables related to computer literacy or trust in the Internet are included in the analysis (Sciarini et al., 2013; Trechsel et al., 2007; Trechsel and Vassil, 2011). In those studies, compositional effects are arguably at work, with age effects being "captured" by the effects of IT-related variables. In other words, it is not age *per se* that influences the use of e-voting, but the fact that tech-savvy people are overrepresented among young citizens, whereas older people are (much) less familiar with – and (much) less confident in – the Internet.

A caveat is in order, however. While existing studies show that age

[3] In other contexts, such as in some municipalities in Ontario, Canada, internet voting has been the only voting mode. Voting contexts also differ with respect to what other voting channels (in-person, mail, or even telephone or e-mail) are available.

influences e-voting use, they vaguely conflate this influence under the term "age effect". That is, they fail to identify whether this influence is due to an ageing, a cohort or a period effect. Starting with ageing effects, differences in political attitudes or behaviors between young and old citizens may result from the natural process of biological and psychological aging, from one's position in the life cycle, or from the experiences that one acquires as time progresses. As people age, their family and occupational status changes, and their experience in different areas increases. Cohort (or generational) effects result from certain events – historical, economic, or political – that leave a footprint on one or more specific generations. Here, age is less important than a person's year of birth, and with the specific experiences that person shares with people of the same cohort. These shared experiences, in turn, promote the internalization of common values and norms, and leads to similar attitudes or behaviors. Finally, and in addition to this, period effects are the result of contextual changes, such as a severe economic crisis, that affect all age groups indiscriminately. In this context, as with any analysis of age effects more generally (Bell and Jones 2024; 2025, 2020), not addressing the identification problem may lead to spurious results regarding these influence of "age" on e-voting use.

2.2. Hypotheses

Our general argument is that the use of internet voting is primarily influenced by cohort effects. The main rationale for this is that the degree of openness to Internet technologies varies across generations (Gilleard and Higgs, 2008). On the one hand, people born after 1980 have grown up with the Internet. As digital natives, they had both access to digital technologies and the skills to use them (Palfrey and Gasser, 2008). The Internet, along with social networks, has become their primary modes of communication (Oostveen and Van den Besselaar, 2004; Gerlach and Gasser, 2009). Young generations are not only highly familiar with the Internet, they are also the group that uses it the most (Powell et al., 2012). Among them, the convenience of e-voting is particularly appealing to "mobile" people who travel frequently for work, as it allows them to vote anytime, anywhere (Ansolabehere et al., 2012).[4]

Older cohorts, in contrast, have discovered Internet later in life and are generally (much) less tech-savvy than younger ones. Many of them still have little familiarity with the Internet and computers in general, and they are also less trusting of modern technologies. While the professional environment is a pathway to technology introduction and adoption (Charness and Boot, 2009), some of these technologies did not exist when older cohorts were working. Both the idea of "digital natives" and the statement about the computer (il)literacy of "old people" clearly suggest the existence of a difference in the use of e-voting between younger and older cohorts.

From this we derive our first hypothesis that *younger cohorts use e-voting more than older cohorts (H1)*.

Going one step further, we assume that in addition to differences between cohorts, e-voting use also varies with age. The Internet is now ubiquitous in everyday life. People use e-banking to pay their bills; they order books, food and clothing from online shops; and they communicate extensively via the Internet or e-mail. The process of Internet diffusion that has taken place over the past twenty-five years has arguably extended to the use of Internet voting. If this expectation of a spillover effect is true, then we should see an increase in the use of e-voting over time. As time goes by and people get older, they are increasingly exposed to e-voting, they learn how to use it and become familiar with it. Accordingly, our second hypothesis states that *the use of e-voting increases with age (*H2).

Hypothesis 2 implicitly assumes that the increase in the use of e-voting with age as a result of the diffusion of Internet technologies and the resulting propensity of voters to adopt and use e-voting holds equally for all cohorts. However, more differentiated effects are likely, in the sense that the diffusion of Internet technologies may have occurred more rapidly in some cohorts than in others. On the one hand, the younger cohorts of digital natives are likely to remain unaffected by the diffusion process, as they have grown up with the Internet and have never known a world without online communication and shopping. Because they have always had these tools at their disposal, a sort of ceiling effect limits the possibility of e-voting diffusion (you cannot learn something you already know). Earlier cohorts, on the other hand, were initially skeptical towards and/or less familiar with the Internet. Over time, they are likely to become more acquainted and more confident with the Internet in general and with e-voting in particular.[5] Therefore, we hypothesize that *the increase in e-voting use with age is stronger among older cohorts than among younger cohorts (H3)*.

3. Data, measures and modelling strategy

3.1. Data

The empirical tests are based on registered data on individual turnout covering the entire electorate of the canton of Geneva, Switzerland. The use of official data on turnout provides a valid measure of participation, and relatedly of voting mode, than the self-reported measure of participation taken from surveys. First, survey data are known to suffer from vote overrepresentation and vote overreporting among respondents (Goldberg and Sciarini, 2019, 2023; Sciarini and Goldberg, 2016, 2017). Second, using registered data also avoids the social desirability problem that plagues survey data on e-voting use, such as whether voters would participate more if internet voting were available (Christin and Trechsel, 2005; Trechsel and Vassil, 2011).

In Geneva, i-voting trials began in 2004 as part of a larger "e-voting pilot project" supported by the Swiss government. These trials, initially limited to four municipalities, were suspended from 2005 to 2008 owing to the lack of legal basis. Since November 2008, the federal legislation has limited the number of citizens who could vote online in federal direct democratic votes to 20 % (until 2011) or 30 % (after 2011) of the electorate. Accordingly, for national votes the State of Geneva offered e-voting to citizens living in selected communes that taken together represented 20 % or 30 % of the canton's electorate, with the set of communes changing over time. For a handful of ballots, when only direct democratic votes on cantonal ballot measures were held, e-voting was available to all citizens. In September 2016, the canton of Geneva implemented new rules regarding the use of e-voting for federal ballots. From October 2016 to June 2019, citizens wishing to vote via the Internet had to register first. Citizen registrations were accepted on a first come first served basis, up to the 30 % limit mentioned above.

As a result of the strong development of direct democracy in Switzerland, citizens are called to vote three to four times a year. Often, cantonal referenda are held in parallel with federal referenda. In addition, federal, cantonal and municipal elections level are held every four or five years. Our dataset covers 46 ballots from September 2004 to May 2019, among which an overwhelming majority of direct democratic votes (40 votes): 30 direct democratic votes involved both federal and cantonal ballot measures (initiatives and/or referendums), six votes involved only national ballot measures, and four votes involved only cantonal ballot measures.[6] Unlike in other contexts such as U.S. states, elections in Geneva cannot be held on the same voting day as direct

[4] This may account for the result of many studies that the second age group of people aged 25 to 29 is the one that e-votes the most (Serdült et al., 2015). Many citizens aged 18 to 25 are still studying or in training and are, therefore, less mobile.

[5] In that sense, it would be wrong to interpret such an effect as a period effect, which is supposed to affect all cohorts and all age groups indifferently.

[6] In three of these four votes, e-voting was offer to all citizens.

Table 1
Descriptive statistics.

Variable	Mean/Percentage
Voting mode	
Other (Postal mail or on-site)	84 %
E-voting	16 %
Birth year	1961
Age	53
Gender	
Man	45.3 %
Woman	54.7 %
Type of voter	
New voter	0.9 %
Zero out of three votes	31.6 %
One out of three votes	17.2 %
Two out of three votes	18.4 %
Three out of three votes	31.9 %
Residence duration	
<10 years	6.2 %
10–20 years	14.3 %
>20 years	79.5 %
Marital status	
Single	25.6 %
Married	53.6 %
Separated/Divorced	14.4 %
Widowed	6.4 %
Cantonal origin	
Geneva	62.3 %
Other Canton	37.7 %

N = 289′603 observations from 20′000 individuals across 46 ballots.

democratic votes; they must be held on a separate date. During the period under study, e-voting was offered for two national parliamentary elections (in 2015), in three cantonal elections (for the *Cour des comptes* in 2012, for the cantonal parliament in 2018, and for the cantonal government in the same year), and one election for the legislative and executive bodies of the municipalities (in 2015).

Our data provide official information on the actual participation (or abstention) of citizens in all of the 46 ballots mentioned above, as well as information on the voting mode used by citizens who participated in a given vote (e-voting, postal vote or vote at the polling station). Moreover, and more importantly, since each individual in the dataset is identified by an anonymized numerical code, we can track his/her participation record and associated voting mode across ballots (Goldberg et al., 2019; Sciarini et al., 2016; Tawfik et al., 2012). Therefore, for every citizen, we have repeated measures over time of both political participation and the associated voting mode. Our registered data set is thus extremely rich and probably quite unique.

However, due to the 30 % limit set by federal regulations, only a minority of Geneva's electorate had the opportunity to vote electronically between 2004 and 2018. Moreover, between 2004 and September 2016, the availability of e-voting varied significantly across municipalities within the canton. While some municipalities offered e-voting regularly, in many municipalities, it was available only on specific voting days, i.e. when only cantonal elections or direct-democratic votes were held, allowing all citizens access. Notably, in more than half of the municipalities (25 out of 45, including the city of Geneva, which represents more than one third of the canton's total population), e-voting was offered in only 3 out of the 35 ballots held between 2004 and 2016. Therefore, we focus the analysis on citizens residing in municipalities where i-voting was available in at least 80 % of ballots during this period (i.e., in at least 28 out of 35 ballots). However, disparities in e-voting opportunities still exist even within this subset. While some citizens could vote online all 35 ballots,[7] others could do so in only 28. To address this, we further refine our analysis by excluding ballots where internet voting was not available in these twelve municipalities.[8]

The institutional change brought about by the pre-registration requirement in November 2016 raises a similar issue: Because we do not have information on individual registration,[9] for the last 11 votes (from November 2016 to May 2019) we cannot distinguish citizens who were able to vote online from those who were not; we must do "as if" all citizens pre-registered and were to vote online, which is obviously a simplification. This means that our analysis provides a conservative test of the use of e-voting, i.e., it underestimates the use of e-voting.

3.2. Measures

The dependent variable in our analysis is the voting mode, specifically the distinction between internet voting and voting via another channel (postal voting or in-person voting). Non-voters are therefore excluded, as the analysis focuses on comparing internet voters with paper voters. As shown by the descriptive statistics in Table 1, the average proportion of internet voters is 16 %. Additionally, figure A1 in the Appendix illustrates that the rate of Internet voting has remained relatively stable, fluctuating only slightly around this 16 % average across votes.[10]

The main variables of interest are the time variables, i.e. the variables accounting for age, period and cohort effects, respectively. Age is the age (in years) of individuals at the time of each ballot. In line with the commonly found curvilinear relationship between age and political participation, we include age in its simple, quadratic and cubic forms in our model.[11] Cohorts are measured by voters' birth year. To test our hypothesis 3, we also include an interaction term between age and cohort. Finally, our measure of period is the ballot in question, thus distinguishing between the 46 ballots covered by our data. It is important to note that while our measure of period is included in the model, it is exclusively integrated into the random part. This allows us to capture random variability and accounts for differences in the institutional type and level of the ballots (direct democratic votes or elections, cantonal and/or federal), as well as the institutional change that has occurred in 2016 in the way e-voting was made available to citizens.

Our model includes a handful of control variables, starting with gender. Empirical evidence on the difference in e-voting use between men and women is mixed (Serdült et al., 2015). Some studies find that men are overrepresented among e-voters compared to women, but this is due to compositional effects (Christin and Trechsel, 2005; Sciarini et al., 2013; Serdült and Trechsel, 2006): the difference in e-voting use between men and women tends to disappear once additional socio-demographic variables or IT-related variables, such as computer literacy, use of and trust in Internet, are included in the analysis.

We also control for voters' marital status (single, married, separated/divorced, widowed), and for length of residence. The latter distinguishes

[7] Only one very small and unrepresentative municipality has offered e-voting in all 35 ballots.

[8] This is not a major drawback, as it leads us to omit 7 ballots in two (small) municipalities, but much fewer in others (in six of the twelve municipalities, e-voting was offered for at least 32 of the 35 ballots).

[9] On the aggregate level, the proportion of citizens who registered to vote electronically has never reached the 30 % threshold. In May 2019, this proportion amounted to 22.12 %. Among them, more than 50 % did vote via the Internet (https://ge.ch/grandconseil/data/odj/020408/PV_FEVRIER2022.pdf).

[10] Figure A1 shows the proportion of i-voting from 2009 onwards, since 2009 is the year of adoption of federal legal provisions for the internet voting trial and, therefore, the year from when e-voting was repeatedly offered. While 16 % of e-voters may seem low, it should again be mentioned that in Switzerland e-voting was offered in addition to the easy-to-use and very popular postal voting system, which has become the dominant voting channel, with 80–90 % of voters in Geneva opting for it, depending on whether e-voting was also available.

[11] By including a cubic term, our model can account for potential inflection points, where the direction of the relationship changes more than once, as is the case with participation – and may be the case with the use of e-voting.

citizens who have lived in Geneva for less than 10 years, for 10–20 years, and for more than 20 years. In addition, we control for citizens' origin, distinguishing between individuals who were born in Geneva or who acquired the Geneva citizenship before the vote in question (e.g., because he or she became a naturalized citizen or acquired Geneva citizenship after moving from another canton) and otherwise 0 (i.e., if he or she votes in Geneva but still holds citizenship in another canton).

Finally, we take advantage of the rich, repeated measures of participation/abstention across all 46 ballots at our disposal to calculate the frequency of citizens' participation in the three votes preceding a given vote. We recalculate the variable for each subsequent vote, which thus provides a dynamic and fine-grained measure of citizens' participation records. This variable then takes four forms (participation in none, one, two, or three of the three previous votes), and compensates for the main limitation of the official database, which only provides information on the handful of socio-demographic characteristics mentioned above, and no information on other common determinants of participation, such as education, socioeconomic status, political interest, or political trust. However, the variable measuring past participation largely reflects the influence of these traditional voting determinants and is widely regarded as one of the strongest predictors of participation in current vote (e.g. Smets and van Ham, 2013).

In addition, we need to take into account the specific category of new voters, i.e. of people aged 18 who have just obtained the right to vote and people who have just acquired Geneva citizenship. A dummy variable helps to avoid missing them for the first three votes; from the fourth vote onwards, they receive the value corresponding to their previous participation record.

3.3. Model

To test our hypotheses, we rely on an *age, period* and *cohort* (APC) approach. As the fictional conversation illustrates, time can be conceptualized in three different but closely related ways (Suzuki, 2012: 452)[12]:

A: I can't seem to shake off this tired feeling. Guess I'm just getting old. [Age effect]
B: Do you think it's stress? Business is down this year, and you've let your fatigue build up. [Period effect]
A: Maybe. What about you?
B: Actually, I'm exhausted too! My body feels really heavy.
A: You're kidding. You're still young. I could work all day long when I was your age.
B: Oh, really?
A: Yeah, young people these days are quick to whine. We were not like that. [Cohort effect]

Thus, age, period and cohorts are three different concepts inherent in the notion of time: *age* obviously refers to the lifetime since birth, *period* identifies the moment when an event occurs, and *cohort* measures an individual's year of birth. In empirical research, however, the distinction between APC effects is not as clear or straightforward as in the fictional conversation above, because the three time-related variables are perfectly correlated (Bell and Jones, 2014, 2015):

Age* = *Period* – *Cohort

The identification problem in APC analyses revolves around the inherent perfect correlation among the three components: Age, Period, and Cohort. Knowing the values of two of these components allows one to infer the third, which poses a significant challenge in disentangling their distinct effects. According to Bell (2020), in causal analysis we can examine the effect of one variable by keeping other variables constant. However, in the case of age, period, and cohort, it is impossible to manipulate one variable without affecting the others. This is because age, period, and cohort are perfectly collinear; fixing any two of these variables automatically determines the third. This complicates the identification of the effect of each variable.

Because of the perfect collinearity among the APC components, it is impossible to estimate the effects of age, period, and cohort independently without imposing some constraints. In short, there is no perfect solution to the identification problem. Excluding one of these components from the fixed effects in the model helps to reduce the number of parameters to be estimated. This simplifies the analytical process by assuming that the excluded component either does not independently influence the outcome or that its influence can be effectively captured by the interactions of the remaining two components. In the present context, the choice of which component to exclude should be consistent with the theoretical assumptions about the primary drivers of e-voting use.

Including only two of the three APC components in the fixed part of a model results in the third component having a linear trend of zero (Bell and Jones, 2020). In our analysis, we focus on age and cohort effects, and we exclude the period component under the explicit assumption that linear period trends do not significantly influence e-voting behavior. This seems a reasonable assumption as, "the mechanism for long-run change is more easily conceptualized through cohorts than periods – change occurring by influencing people in their formative years rather than 'something in the air' that influences all age groups equally and simultaneously" (Bell and Jones, 2015: 203).

We run a multilevel mixed-effect model. Specifically, we include age and cohort in the fixed part of the model and period in the random part. As we have just mentioned, the model assumes the absence of period effects by not including a fixed effect for the linear period trend. However, the model accounts for potential variability across periods by including random effects, which capture period-specific deviations from the overall trend. In addition, to address the longitudinal structure of our data, i.e. the fact that we follow individuals over time, we include an individual level in the random part. As a result, each observation corresponds to the pairing of an individual and a ballot. Consequently, our unit of analysis is the individual-ballot combination. This results in a cross-classified model in which occasions are nested in individuals and periods (ballots), as summarized in Fig. 1.

In this multilevel binomial model, the parameters are estimated for e-voting and abstention, compared to voting at the polling station or by postal mail:

$$\log\left(\frac{p_{\text{E-voting}}(x)}{p_{\text{Other}}(x)}\right) = \alpha_0 + \beta_1 \text{Birth year}_{ijk} + \beta_2 \text{Age}_{ijk} + \beta_3 \text{Age}^2_{ijk} + \beta_4 \text{Age}^3_{ijk} + \beta_5 \text{Woman}_j + \beta_6 \text{Residence}_{ijk} + \beta_7 \text{Marital status}_{ijk} + \beta_8 \text{Origin}_j + \beta_9 \text{Type of voters}_{ijk} + \beta_{10}\left(\text{Birth year}_{ijk} \cdot \text{Age}_{ijk}\right) + \nu_{jk} + \mu_k \quad (1)$$

This equation accounts for the probability to e-vote compared to vote

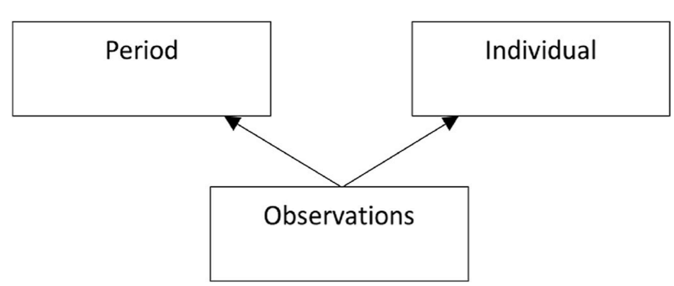

Fig. 1. Cross-classified data structure.

[12] This fictional conversation is taken from Bell and Jones (2014, 2015).

Table 2
Binomial multilevel logistic regression (e-voting versus other voting mode).

	E-Voting (SE)
Birth Year	0.608*** (0.120)
Age	−1.182*** (0.116)
Age^2	0.826*** (0.071)
Age^3	0.132*** (0.020)
Woman	−0.642*** (0.081)
Residence <10 years	0.035 (0.070)
Residence 10–20 years	−0.090* (0.045)
Married	−0.166* (0.077)
Divorced	−0.562*** (0.102)
Widowed	−0.331* (0.147)
Other Canton	0.105 (0.079)
One vote out of three	0.210*** (0.035)
Two votes out of three	0.238*** (0.035)
Three votes out of three	0.280*** (0.037)
New Voter	−0.285*** (0.075)
Birth Year * Age	1.400*** (0.090)
Constant	−4.840*** (0.132)
Observations	286,698
Akaike Inf. Crit.	124,507.000
Bayesian Inf. Crit.	124,707.800

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

with another voting mode for a citizen j in a given ballot k. i corresponds to the ballot-individual combinations, since each observation refers to an individual in a given ballot. υ_{jk} and μ_k are the group parameters for individuals and ballots.

Given the large volume of data (more than 2.2 million observations over the entire period) and computational capacity constraints, we conducted our model estimation on a randomized stratified sample of 20′000 individuals. This sample in turn represents 289′603 observations distributed across the 46 ballots under study.

4. Results

Table 2 presents the results of a cross-classified logit model that distinguishes e-voting from voting through another channel (by postal mail or at the polling station). The coefficient for year of birth is positive. This suggests that the use of Internet voting (rather than another voting mode) is more common among later (i.e. younger) cohorts than among earlier (i.e. older) cohorts. In addition, the interaction term between age and cohort is positive.[13] This suggests that the age effect is greater for younger cohorts than for older cohorts. Unlike expected, however, the effect of the simple term for ageing is negative, whereas the quadratic and cubic terms are positive. Because age and cohort are embedded in interaction terms, it is difficult to assess their effects based on coefficients, especially in a logit model (Brambor et al., 2006; Kam and Franzese, 2007). Therefore, we rely on the predicted probabilities to get a clearer view of the effects (Fig. 2).

Fig. 2 shows the predicted probabilities of voting online by age for people born in 1930, 1933, 1936, …, 1993, and 1996. Several key findings emerge. First, looking at the curves for years of birth, middle cohorts born between the mid-1960s and mid-1980s exhibit a higher probability of using e-voting than both younger cohorts born in the 1990s and, even more so, older cohorts born in the 1950s or earlier. However, the cohort effect varies across age groups. Among voters aged 20 to 50 (left-hand side of the figure), and contrary to expectations, earlier cohorts show a higher probability of voting online than later ones at the same age. For instance, a 30-year-old born in 1987 has a 0.14 probability of voting online, whereas a 30-year-old born in 1975 has a much higher probability of 0.34. The cohort effect weakens for middle-aged individuals (40–45) and disappears for those aged 50 and older. Thus, while our results partially support our first hypothesis – confirming that younger and intermediate cohorts use e-voting more than older cohorts – the expected differences within these younger and intermediate cohorts are not in line with our hypothesis.

Second, Fig. 2 reveals a non-monotonic effect of age across cohorts. On the one hand, we see a strong age effect among intermediate cohorts of voters born between the mid-1950s and early 1980s, but one that runs counter to our hypothesis 2. Instead of an increase in e-voting use with age resulting from a learning or habituation process, we observe a marked decline. For instance, among individuals born in 1969, the probability of voting online drops from 0.32 at age 35 (in 2004) to 0.11 at age 50 (in 2019). On the other hand, for the youngest cohorts (born in the 1990s) and the oldest cohorts (born in the 1930s and 1940s), aging has little to no effect, with e-voting use approaching zero among the latter, regardless of whether voters are 60 or 80 years old. Consequently, these findings also contradict our third hypothesis, which predicted a stronger increase in e-voting use with age among older cohorts than among younger ones.

Taken together, these nuanced findings reveal the interplay between cohort and age effects in shaping e-voting behavior. Contrary to the common assumption that digital natives – those born in the late 1980s or 1990s – are the most active e-voters, our results identify voters born in the 1970s as the primary adopters. This aligns with previous research (e.g., Serdült et al., 2015), which also found that e-voting usage peaked among individuals aged 30 to 40 rather than the youngest voters. However, by disentangling cohort and age effects, our study refines these earlier conclusions and provides deeper insights into how age dynamics influence e-voting adoption. Specifically, we show that the peak in e-voting use is driven by a combined cohort and age effect, spanning from voters in their mid-20s born in the late 1970s to those in their mid-30s born in the early 1970s. Yet, our findings also highlight a sharp decline in e-voting participation as these cohorts age.

One possible explanation for this decline is a diminishing novelty effect: when e-voting was first introduced, its innovative nature may have appealed particularly to those who were already eligible to vote, encouraging early adoption. As the novelty wore off and alternatives such as postal voting remained a convenient option, the initially high rates of e-voting use among these cohorts declined over time. While this mechanism is likely to be most relevant for these early adopters, voters who reached voting age after e-voting had become established (i.e., those born in the 1990s) may not have experienced this initial surge of enthusiasm. Another possible explanation for the decline in i-voting usage among intermediate age cohorts is that support for internet voting has waned over time due to increasing security concerns regarding the reliability of the e-voting system.

Commenting briefly on the control variables, the coefficient for women in Table 2 indicates that they use e-voting less than men. Marital status also makes a small difference: Widows and, to a lesser extent, married and divorced voters are less likely to vote online than singles, the reference category. The coefficient for the variables measuring citizens' participation record is positive and significant for all three categories (Table 2). This suggests that people who abstained in the last three votes are less likely to vote online in current vote. The use of e-voting is also lower among new voters.

4.1. Robustness test

As a first robustness test, we estimate a model with the same specification as in Table 2 but restricting the sample to the six municipalities that offered e-voting in more than 90 % of the votes (see Table A1 in the Appendix). The results remain the same. Second, we run two additional models to ensure that the negative effect of age is not driven by the change in the internet voting system implemented in 2016 (shifting from

[13] We also tested a more complex model with an interaction between birth year and the quadratic form of age. As the parameter was not credible, we followed Bell and Jones' recommendation and reverted to the simpler model appearing in Table 2.

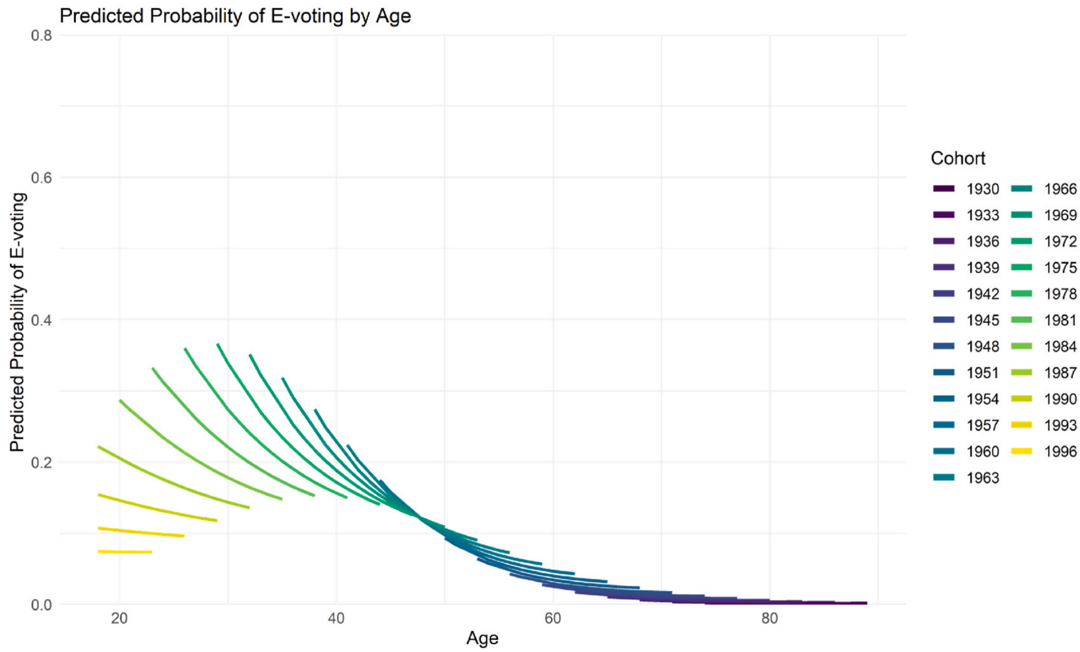

Fig. 2. Predicted probabilities to e-vote across age and cohorts.

a municipality-based selection to an individual sign-up system). The first model includes a dummy variable for ballots held after September 2016, while the second excludes ballots from the post-September 2016 period. In both models the effect of age remains negative –and gets even stronger (see Tables A2 and A3 in the appendix), which demonstrates that the observed relationship between ageing and e-voting usage is not an artifact of the system change.[14]

5. Conclusion

Age, period, and cohort effects represent distinct mechanisms through which the use of internet voting evolves over time. Due to data limitations, previous research has struggled to disentangle these effects. Our study addresses this gap by applying an APC approach to a comprehensive dataset of registered voter participation spanning sixteen years and 46 ballots.

Our findings provide empirical evidence of both cohort and age effects, as well as their interactions. First, the use of internet voting is higher among intermediate cohorts, than among younger and, even more so, among the oldest cohorts. Second, contrary to our expectations, e-voting use declines with age within these intermediate cohorts, rather than increasing. As a result, e-voting usage peaks among individuals in their mid-20s to mid-30s who were born between the early and late 1970s. For older cohorts, the age effect is close to zero – these cohorts hardly use e-voting at all. Thus, our findings challenge the assumption that digital natives are the primary adopters of e-voting, instead revealing that its peak usage emerges from a combined cohort and age effect.

The cohort and age effects on i-voting use uncovered in our study have important implications. It is well known that the entry into the electorate of new generations with a lower sense of civic duty has been a major driver of turnout decline in Western countries (Blais et al., 2004; Franklin et al., 2004). Our results do not support the notion that offering internet voting as an additional voting method can significantly counteract declining participation. Young cohorts do not make intensive use of e-voting, and its adoption does not increase with age within these groups, thereby limiting its potential impact on overall voter turnout.

However, assessing the direct effect of e-voting on turnout falls beyond the scope of this study.

For as the bottleneck approach to e-voting convincingly argues, one needs to distinguish the usage of e-voting from its impact. In that context, it should be mentioned that the modelling strategy used in existing studies analyzing the impact of e-voting on turnout does not allow to separate cohort from age effects, as we do in this paper. Therefore, looking at the effects of e-voting on turnout from an APC perspective seems a promising avenue for research. Of course, such an avenue would be even more promising if one could extend the time frame of the study.

Unfortunately, in June 2019, the Swiss Federal government decided to put the e-voting experience on hold for security reasons.[15] This sudden decision prevented voters from using internet voting and put an end to our data series. While a period of sixteen years already provides reliable data for an APC analysis, the shortness of the panel remains a potential limitation.

Meanwhile, the Covid-19 pandemic has highlighted the paramount importance of Internet communication, be it for education, professional activities, or leisure and socializing. It is therefore safe to assume that e-voting will gain new support and will become widely available in the near future. In fact, in Switzerland, e-voting has been relaunched as a pilot project in 2023 in three cantons (Basel-City, Thurgau and St-Gall) based on an updated and more secure technology offering full (or so-called “universal”) verifiability. The canton of Geneva will hopefully follow soon.

In light of these recent developments, we also point to out-of-time cross-validation as a promising avenue for future research. Newly available data will provide an opportunity to replicate our model on a new – or longer – dataset, and test whether the above assumptions hold.

[14] Unsurprisingly, in both models the cohort effect gets non-significant. In the first model, the dummy variable for post-September 2016 ballots partly absorbs the cohort effect, as younger cohorts are overrepresented after 2016, while older cohorts are more prevalent before 2016. In the second model, excluding post-September 2016 ballots significantly shortens the time span of the analysis, limiting the ability to estimate cohort effects.

[15] Earlier that year, a public intrusion test revealed serious flaws in the system’s source code of the Swiss Post, the only remaining provider of e-voting.

Such an approach will allow for comprehensive validation and ultimately increase the generalizability and external validity of our findings.

CRediT authorship contribution statement

Moulay Lablih: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Data curation. **Pascal Sciarini:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A1
Binomial multilevel logistic regression (90 %)

Dependent Variable:	E-Voting (SE)
Birth Year	0.567*** (0.139)
Age	−1. 162*** (0. 134)
Age^2	0.768*** (0.081)
Age^3	0.115*** (0.023)
Woman	−0.586*** (0.096)
Residence <10 years	−0.030 (0.083)
Residence 10–20 years	−0.095* (0.053)
Married	−0.192* (0.094)
Divorced	−0.604*** (0.123)
Widowed	−0.282 (0.173)
Other Canton	0.167 (0.095)
One vote out of three	0.174*** (0.041)
Two votes out of three	0.201*** (0.042)
Three votes out of three	0.260*** (0.044)
New Voter	−0.260*** (0.090)
Birth Year * Age	1.351*** (0.105)
Constant	−4.949*** (0.161)
Observations	203,767
Akaike Inf. Crit.	88,877.010
Bayesian Inf. Crit.	89,071.280

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table A2
Binomial multilevel logistic regression (post-September 2016 dummy)

Dependent Variable:	E-Voting (SE)
Birth Year	0.038 (0.157)
Age	−1. 735*** (0. 152)
Age^2	0.798*** (0.072)
Age^3	0.131*** (0.020)
Woman	−0.640*** (0.080)
Residence <10 years	0.037 (0.070)
Residence 10–20 years	−0.088* (0.045)
Married	−0.165* (0.077)
Divorced	−0.560*** (0.102)
Widowed	−0.327* (0.147)
Other Canton	0.105 (0.079)
One vote out of three	0.208*** (0.035)
Two votes out of three	0.235*** (0.035)
Three votes out of three	0.273*** (0.037)
New Voter	−0.285*** (0.075)
Post-September 2016	0.360*** (0.065)

(*continued on next page*)

Table A2 (*continued*)

Dependent Variable:	E-Voting (SE)
Birth Year * Age	1.362*** (0.090)
Constant	−4.955*** (0.133)
Observations	286,698
Akaike Inf. Crit.	124,478.200
Bayesian Inf. Crit.	124,689.500

Note: *p < 0.05, **p < 0.01, ***p < 0.001.

Table A3
Binomial multilevel logistic regression (2004–2016)

Dependent Variable:	E-Voting (SE)
Birth Year	−0.038 (0.152)
Age	−1. 948*** (0. 152)
Age^2	0.629*** (0.097)
Age^3	0.178*** (0.025)
Woman	−0.682*** (0.083)
Residence <10 years	0.085 (0.085)
Residence 10–20 years	−0.160** (0.054)
Married	0.042 (0.092)
Divorced	−0.474*** (0.122)
Widowed	−0.230 (0.169)
Other Canton	0.154 (0.082)
One vote out of three	0.022 (0.040)
Two votes out of three	−0.007 (0.041)
Three votes out of three	−0.063 (0.043)
New Voter	−0.098 (0.089)
Birth Year * Age	1.045*** (0.112)
Constant	−4.611*** (0.142)
Observations	211,289
Akaike Inf. Crit.	96,844.990
Bayesian Inf. Crit.	97,039.950

Note: *p < 0.05, **p < 0.01, ***p < 0.001.

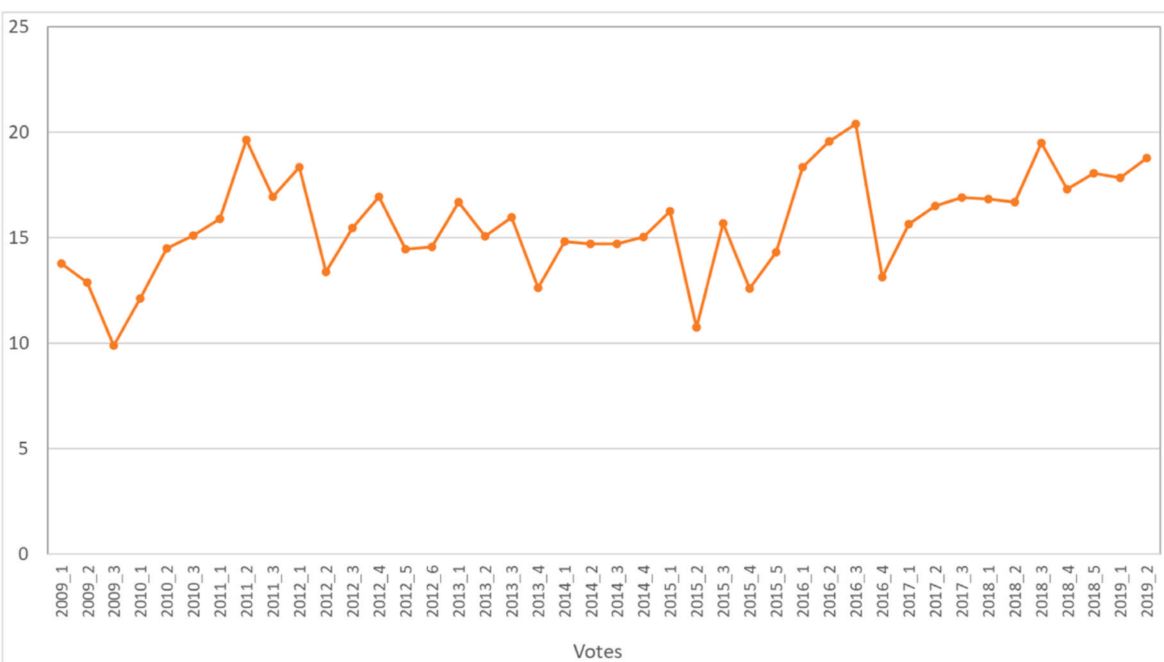

Fig. A1. Rate of e-voting use across votes (in %)

Data availability

The data that has been used is confidential.

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