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Technological Limitations to the Cost Saving Effect of Remote Internet Voting

Master's thesis

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Abstract

This thesis examines remote internet voting (I-voting) in the context of the Downsian (1957) theory of rational voters. I-voting could potentially raise turnout by providing a lower cost method for casting a vote, but only if the technology used is not a hurdle for adoption. Using data from the Estonian E-voters survey I-voters are contrasted to regular voters and change over the time span of 2007 to 2011 is examined. Findings indicate that there is a large difference between the initial cost of I-voting between different levels of technological aptitude, differences remain largely intact over time. When the regular cost of voting becomes too high, even the least adept might vote online.

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1. Introduction

The widespread use of internet presents us with a unique opportunity - voting from the convenience of your home, or any other remote location from the polling station. So far remote internet voting has only rarely been used, but the idea seems promising. Can citizens be enticed to vote by offering them a more convenient way of voting? Does I-voting reduce the cost of participation and if yes, how does it change over time?

Electoral turnout is regarded as a central indicator for democratic health, elections are a central premise for the political legitimacy of a democracy (Bhatti & Hansen, 2012). Meanwhile researchers agree on the declining voter turnout in recent decades (Gallego, 2009). The introduction of remote internet voting or I-voting was hoped to bring about a boost in turnout, however after some initial trials no major change in turnout was observed.

The aim of this thesis is to take a closer look at the Estonian case, where I-voting has been an option for a decade now, and observe how technological factors are affecting I-voting over time. The potential effects of I-voting will be integrated into the general framework of the Downsian (1957) economic theory of voting.

At first a general overview of I-voting will be presented, with a focus on Estonia and previous findings in the field.

The choice between paper ballot and I-voting will be put into the context of Downsian (1957) model of economic voting, where rational actors balance their costs of voting against perceived gains. According to the theory citizens gaining a more convenient mode of voting should quickly adopt it and in some instances choose I-voting instead of abstaining, thus leading to a rise in turnout.

Technological limitations are introduced to explain the more gradual pattern of adoption witnessed so far in Estonia. Unfamiliarity with computers or the internet might limit the usefulness of I-voting. If the technology used for online voting is a limiting factor in itself, potential gains from using I-voting will only be realized by some, limiting the potential boost to turnout.

Using Rogers' (1995) theory of diffusion and van Dijk's (2005) conceptualizations of digital divide, conclusions are made about how the relationship between technological aptitude and I-voting should change over time.

The raised assumptions are later tested on data gathered in Estonia between 2007 and 2011. For the first time different elections with I-voting are compared and change over time is measured. Finally conclusions are made in the context of the economic theory of voting.

Only the social aspect of technology is discussed. Issues of online security, transparency, costs of running elections or the like are beyond the scope of this thesis.

2. Theoretical framework

2.1. I-voting

There are several different methods of electronic voting, including voting machines in the ballot station and on site internet voting. The theme of this thesis will be solely remote internet voting. E-voting can refer to both remote internet voting and electronic voting in general. For the sake of clarity the term I-voting will be used to avoid confusion with other modes of electronic voting.

There was initially much optimism for the consequences of I-voting on voter turnout and political representation (Smith & Clark, 2005). One of the main reasons voting online might increase turnout is its ability to decrease the cost of participation (Smith & Clark, 2005) (Carter & Campbell, 2011). This enthusiasm has since declined as no large boost to turnout has been observed (Gerlach & Gasser, 2009).

A modernization of the voting process and the inclusion of new voting technologies might boost voter turnout. I-voting might also raise turnout by appealing to young people (Gerlach & Gasser, 2009), among whom turnout has been low throughout European democracies (Gallego, 2009).

Other possible positive consequences of I-voting include the extension of political rights to citizens who are disabled or living abroad (Gerlach & Gasser, 2009). It can also improve the quality of voting by making sure no one casts an illegible ballot (Gerlach & Gasser, 2009). Joining the computer as both means of casting a vote and primary source for information, including looking up information while voting might improve the quality of voting (Solvak, Vassil & Vinkel, 2014).

Along with the possible benefits of I-voting some authors have also voiced concerns. Gerlach and Gasser (2009) point out that, with a faster option of voting, voters might also see fewer reasons to discuss their views with others and make less informed choices. If voting only takes a minute it might encourage voters to make on the spot decisions. I-voting lacks the ritual component of voting, which might be an incentive to vote in itself (Gerlach & Gasser, 2009).

Estonia has been the only country where voters have had the chance to cast a binding vote online in a nationwide election. There have been a handful of trials in other countries, results suggest no

or little positive effect from I-voting to turnout. For example I-voting in Switzerland did not provide a significant augmentation to voter turnout (Gerlach & Gasser, 2009).

2.2. I-voting in Estonia

I-voting has been available since 2005 local elections, during eight elections over ten years, the number of people using the new method has generally increased, starting at 9 287 votes (1.9% of all votes cast) in 2005 and peaking in the 2015 national parliament elections at 176 329 (30.5% of all votes cast) (National Electoral Committee, 2015). The change over ten years is staggering, online voting has become common practice, with a third casting their vote online.

Providing a reliable estimate on the increase in voter turnout caused by the possibility of I-voting has proved to be difficult, since there is no way to measure the turnout in the counterfactual scenario where I-voting is absent (Kirstjan Vassil, 2013).

The turnout of elections with I-voting has been larger than preceding elections of the same level in, this might be the result of normal fluctuations in turnout or the result of the mobilizing effect of I-voting (Kirstjan Vassil, 2013).

Based on survey results (discussed below) up to 3.5% of voters would have abstained had there been no opportunity to vote online (Kirstjan Vassil, 2013). This is based on answers to the question " If You didn't have the possibility to vote online, would You still have voted?", the result of self-reported behavior in a counterfactual situation is somewhat suspect.

Previous research in Estonia has offered some insight to the adoption of I-voting.

Distance to the polling station can be used to measure the cost of voting, i.e. if it takes more time for someone to move to the polling station, then casting a paper ballot is costlier. High electoral costs hinder traditional participation, which in turn motivates people to opt for internet voting as a means to reduce these costs. The distance to the polling station and the probability for I-voting are clearly linked- people living further away from a polling station having a higher chance to be I-voters than paper ballot voters (Solvak, Vassil & Vinkel, 2014).

Weber and Vassil (2011) suggest that limiting the possible beneficial effects of I-voting is a bottleneck effect - the people most likely to benefit from I-voting are peripheral citizens for whom using the new technology is interesting and who might have had difficulties voting using conventional means, however these citizens are also the least likely to participate in the first place. Those more likely to participate are also more likely I-voters, for them the method is more convenient, however they are not mobilized, since they were likely to vote without I-voting. Weber and Vassil conclude that I-voting can boost turnout, but initially benefits the elite, who are already politically active technology users. They also point out that the neck of the bottle might widen as the technology of I-voting gets widely adopted, in which case turnout increases. It is also possible that the mobilizing effect of I-voting disappears when the technology becomes commonplace.

Solvak and Vassil (Solvak & Vassil, 2014) used data available from the 2005 to 2013 elections in Estonia to contrast the profile of first time I-voters and regular voters. Based on Rogers' (1995) theory of technological diffusion the differences between regular and I-voters should diminish over time if the technology gets adopted. I-voters used to be ethnic Estonians from a distinct age group, who have good PC skills, and trust the e-voting system, however after the first three I-enabled elections it becomes harder to predict I-voters based on socio-demographic and attitudinal data. This suggests that over three elections in a time span of four years I-voting has diffused significantly.

2.3. The economic theory of voter turnout

Rational choice theory will be used for this thesis because it offers easy explanations for the possible effect of voting costs. Rational choice theory must not be seen as opposed to sociological or psychological explanations of voting, instead it can be used to give systematical framework to use the latter (Falter & Schoen, 2005: 244-5), This is also the direction taken in this thesis, after the technological factors are introduced.

The most influential author on economic theory of voting is Robert Downs, whose book "An Economic theory of Democracy" laid the foundation for a large body of work in the field (Falter & Schoen, 2005:250).

Each voter incurs some form of cost for participation (Downs, 1957). The cost is primary from getting informed about the choices, however a portion of the costs also relates to the act of voting itself, for example the time spent going to the polling station cannot be used to do other activities (Downs, 1957: 265).

The potential voter will decide if the costs of voting are higher than his or her perceived gain from casting a vote. One vote can hardly ever decide the outcome of any election, which leads to a well-known paradox of voting, i.e. according to the theory rational voters would always abstain. There are several solutions in the literature to overcome the issue (Falter & Schoen, 2005: 284-292), Downs himself suggests that there is inherent gain from voting in itself, since only a certain degree of participation can keep democracy working and its downfall would have obvious and catastrophic consequences (Downs, 1957: 270). There are other similar solutions to the paradox that suggest either social or psychological gains from voting, like the approval of peers, which bring back social factors that Downs ignored (Falter & Schoen, 2005: 292).

The cost of voting is usually tiny, but since the perceived gain of voting is also small (Aldrich, 1993), even minor changes to the convenience of the voter can increase turnout (Feddersen, 2004). For example it is known, that turnout is lower if elections are held on a rainy day (Gomez, Hansford & Krause, 2007). There are also more "errors" by decision makers, when the costs and benefits are low, thus models predicting turnout are less reliable than similar models of participation (Aldrich, 1993).

Remote internet voting should make voting more convenient, thus reducing its cost, at least for some citizens. Thus, some citizens should start using the new method, because it is less costly for them. More importantly some, who previously would have abstained, should vote, since the cost of voting for them has decreased. Turnout should increase with the introduction of I-voting, however not by a lot, as it would only mobilize voters for whom the reduction of costs crossed the tipping point.

This leads to two conclusions: first I-voting will be widely used, because it is the less costly method in most cases. Secondly, turnout will somewhat increase with the introduction of I-voting, because for some citizens costs were decreased and costs did not rise for anyone, since

the new method is optional. The first conclusion would be easily observable and, in the case of Estonia, true. The second conclusion is not directly observable- the effect of I-voting cannot be isolated from normal fluctuations in turnout.

The switch from paper ballot to I-voting should happen immediately, as rational voters should adopt a cost efficient method at first opportunity. This was however not the case as usage of I-voting went from 1.9% in 2005 to 30.5% of all votes cast in 2015 (National Electoral Committee, 2015). What prevents citizens from potentially profiting from I-voting? One possible solution is that the technology used for I-voting is a barrier for switching to new mode of voting.

2.4. Technological barrier and diffusion

The technological barrier is twofold: First there is the question of how much time the adaption to the new technology will take? As a new technology becomes available, it will not be used by everyone immediately, different types users will adopt the innovation over a at different time points (Rogers, 1995). The second issue is accessibility, amongst whom will the technology take hold? Any innovation can only be adopted by those who have access to the prerequisite technology, skills, access etc. For example any innovation that uses the internet has a barrier to entry for anyone who is not a regular computer user or who has no internet connection.

2.4.1. Elements of diffusion

Diffusion is a process by which innovation is communicated through certain channels over time among the members of a social system. When new and beneficial technology becomes available, its adoption is not guaranteed, even if the benefits seem obvious (Rogers, 1995: 7-8). The diffusion of an innovation depends on the characteristics of that technology, on the way it is communicated, on the passage of time and the social system where the diffusion takes place. Diffusion can fail, if the technology is rejected.

Diffusion depends on communication of ideas, as people are generally more likely to adopt innovations based on subjective evaluation by their peers. This transfer of ideas occurs most often among similar people (Rogers, 1995: 18-19).

The rate of adoption is measured by the length of time required for a certain percentage of the population to adopt an innovation. When the number of individuals adopting the innovation is plotted on a cumulative frequency basis over time, the resulting distribution is an S-shaped curve. There is of course variation in slope and the shape of the curve (Rogers, 1995: 22-23).

Finally the social structure of the system affects the diffusion of an innovation. The system affects diffusion through norms, the role of opinion leaders and change agents, the type of innovation-decisions (individual or collective decisions on innovation) and consequences of innovation (Rogers, 1995:23-29).

2.4.2. Cost effects

People who could benefit from the possibility of I-voting must adopt that innovation in order to realize those benefits. As said earlier, the simple fact that some technology is advantageous does not automatically lead to its adoption. Some diffusion of I-voting is taking place as is evident by the number of people who used it to cast their vote. However the general number of I-voters tells us nothing about who they are. Are the adopters people who benefit the most from this technology, e.g. people for whom casting a paper ballot is more difficult? Is the technology spreading over time to people who would benefit from it?

Relative advantage of a new technology has been found to be one of the best predictors of innovation's rate of adoption (Rogers, 1995: 216). Relative advantage indicates the benefits and the costs of adopting an innovation. In the case of I-voting the most obvious benefit is the time saved from voting quickly online compared to going to the physical polling station. There is also an added bonus of comfort from not having to leave the house and not being bound by the time of day (useful for long shift workers). Another possible advantage is that the technology used for I-voting is interesting by itself, so that the novelty might actually be a benefit, however even if that is true the effect should quickly wear off.

The advantages are not the same for each citizen, someone whose designated polling station is in the department store that they visit every day is going to profit a lot less than someone who lives in a rural area and has to take the bus to reach his polling station.

The second aspect of relative advantage is the cost of adoption (Rogers, 1995: 216). Casting a vote online is easy in theory. However the used technology itself might be a hurdle for some citizens- not everybody uses or is familiar with computers, the internet or ID cards.

According to van Dijk (2005) inequality in internet communication technologies and thus possible differences in adoption can be grouped into four categories. First there is motivation to use new technologies, if there is no will to use new technology adoption is unlikely regardless of other factors. Secondly physical access is determined principally by owning the necessary devices or having some other form of access (for example using a family member's computer). Third, inequality of skills represents the level of competence in using new technologies. Finally inequality of usage is the differing frequency and amount of actual usage (Van Dijk, 2005: 20-22).

Motivation to use the new technology comes from its previously described advantages. Since the relative advantage posed by I-voting varies from person to person, the incentive to adopt the technology and thus motivation also varies.

Physical access is generally not much of an issue in Estonia, where personal computers and an internet connection are common place in most households. An ID-card reader is required, they cost around 10 Euros and are available from electronics stores and larger supermarkets (the same readers are also used for online banking and digital signing of documents), as an alternative identification through mobile phone with a special sim card is also possible.

Skill and usage are of primary interest in the context of online voting. If we presume that someone who has already made up their mind about voting is going to choose the most convenient method of casting that vote, naturally people with a higher level of computer skills will find online voting more convenient. At the same time people with poor computer skills might find the procedure intimidating. Finally people who are used to doing many activities online might be more inclined to vote online.

Carter and Cambell (2011) ran a small scale survey of US citizens, measuring their intention vote online, if it would be possible in the US. Trust in internet transactions and accessibility were of

primary importance in the intention to vote online. They also found that people who use the internet for other services are not necessarily inclined to adopt Internet voting (Carter & Campbell, 2011). This gives reason to believe that heavy internet users might not be automatically inclined to use I-voting.

2.4.4. Time effects

Rogers' (1995: 261-275) theory of diffusion divides adopters into categories based on innovativeness, how likely they are to adopt an innovation. In case of complete adoption people can be categorized based on the time they adopted the innovation compared to the mean time of adoption. The first to adopt are Innovators (<-2 standard deviation units), then come the Early adopters (-2..-1sd), then Early Majority (-1..0sd) followed by the Late majority (0..+1sd) and finally the Laggards (>+1sd). There are no pronounced brakes of innovativeness between the categories, rather they are abstractions of empirical patterns.

There are preliminary findings on how adopters in Estonia differ from non-adopters. General socio-demographic variables become weaker in predicting the use of I-voting (Solvak & Vassil, 2014), which means that I-voters have become more heterogeneous over time. Since similar groups of innovators are generally homogenous, this result indicates that diffusion is taking place. What is unknown is how much previous affinity (or lack thereof) with related technologies is aiding or hindering the possibly beneficial adoption of I-voting.

Van Dijk (2005) describes the Mathew effect of using information and communication technologies, where the usage gap widens, as a result of those with the most resources being the first to adopt new technologies and thus gain even more resources. Van Dijk presents two different models in explaining how differing sub-groups adopt new technologies. Normalization - the differences between groups increase over time in the beginning, until the leading group saturates and others catch up. The other option is stratification -rate of adoption in both groups goes through the same stages of acceleration and saturation, but there is a different point of departure for higher and lower strata and a different point of arrival. Van Dijk argues that the stratification model fits better to explain the technological divide in the long term (Van Dijk, 2005: 65-66).

In the context of I-voting the normalization model would predict that skillful and frequent internet users will be overrepresented in the first elections where I-voting is implemented, but others will catch up and there will be no difference in later elections. The stratification model predicts that the gap will not close and I-voting remains more likely among frequent internet users.

2.5. Hypotheses

Presuming that voters will choose the method with the lowest cost to cast their vote, there should be a clear relationship between the cost of regular voting and usage of I-voting. Increased costs of regular voting should make I-voting a preferable option.

Hypothesis 1: As the cost of conventional voting increases, the probability of I-voting increases.

People with high computer skills and regular internet users are likely to adopt to I-voting first, they are usually also already highly motivated to participate in elections, thus giving them another method to cast their vote, but not mobilizing them (Vassil & Weber, 2011). The cost saving effect of I-voting will not be mobilizing, since the politically engaged were likely to vote in the first place. In order for I-voting to realize its full cost saving potential the technological divide must not be an issue. If low skill or habit in using the internet are a barrier to casting an I-vote, it might not be more convenient to vote online than to vote regularly, since there is the added cost of using unfamiliar or uncomfortable technology.

If the rising costs of regular voting have a similar effect among different levels of technological aptitude, then the technological barrier has no real effect on I-voting. The mode choice will depend on usefulness and not on previous skill or habit. However a more likely scenario involves some effect of technological aptitude on I-voting, with more frequent internet users and people with higher computer skills being more likely to use the mode and non-users being unlikely to vote online even if regular voting costs are high.

Hypothesis 2: The increase of the probability of I-voting as a function of the increasing cost of conventional voting is conditional on the level of technological skills.

Estonia presents a unique case where data is available for several consecutive elections using I-voting. If diffusion of I-voting takes place I-voters and regular voters should become more similar to each other. There is some evidence in this regard, the socio-demographical background of I-voters and regular voters has become more similar (Solvak & Vassil, 2014). The predictive power of computer literacy and frequency of internet use should decline in a similar manner, indicating that the normalization model holds true. Under the normalization model over time different levels of technology users become more similar in their use of I-voting .

Hypothesis 3: The predictive power of the technological factors decreases over time

The predictive power should remain constant if the stratification model holds true. In this case one would expect the differences of the likelihood of I-voting among different levels of technology users to remain constant. The barrier to I-voting might decrease, but the difference between individual levels of technology users can remain constant.

3. Method

3.1. Data

This thesis will use the data from the Estonian I-voters survey that has been conducted from 2005 to 2015. During these years specific items have been changed and replaced rendering parts of the data set incomparable. For this thesis only data from 2007 (National elections), 2009 (European parliament and Local elections) and 2011 (National elections) will be used.

Data were collected by AS Emor. Random stratified sampling was used to collect an equal share of I-voters, regular voters and abstainers. Data was collected by CAPI interviews taking place a few weeks after the corresponding elections.

Pooled data will be used to test the first two hypotheses, for the final hypothesis each election will be considered separately. The sample sizes for each election are 2007 n=982; n=997 (European parliament) and n=1000 (local) in 2009 and n=1007 in 2011.

There have been three different types of elections over the time period in question with data available: local (2009), national (2007,2011) and European parliament (2009). It is known that the electorate for different levels of elections differs somewhat. Thus some differences between the years are to be expected regardless of time effects.

3.2. Variables

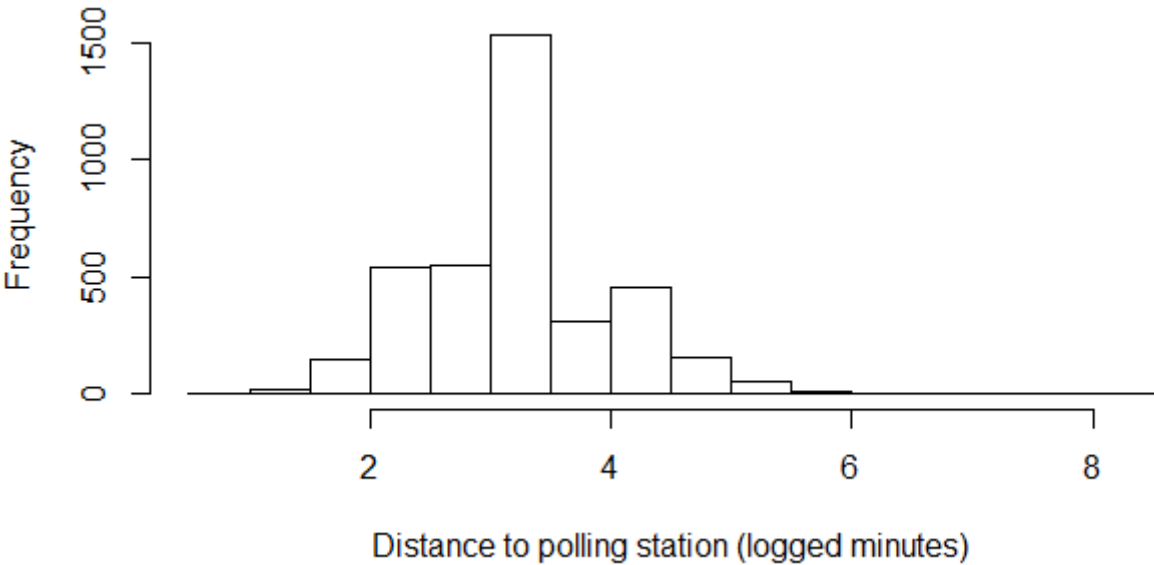
Mode choice - The dependent variable used in all models is the mode of voting, i.e. did a voter cast their vote online (coded 1) or use a regular paper ballot (coded 0)? Paper ballot voters are those who either participated on election day or by advanced polls at the polling station. I-voters are those who participated in advanced voting by the internet. There are also other modes of casting a vote in Estonia, but none of them were observed in the sample. For each year a sample including an equal share of I-voters and regular voters was selected (as far as possible). The final pooled sample includes 1312 regular voters and 1430 I-voters.

Cost of voting - The main costs of voting is gathering information, which is the same for both I-voting and paper ballot voting. The differing cost between the methods is the act of voting itself,

with the assumption that I-voting is the easier, thus less costly option in many cases. This thesis will use the logged distance to the polling station to measure relative cost of casting a paper ballot, the same measure was used by Solvak, Vassil & Vinkel (2014).

Survey participants were asked how long it would take them to go to the polling station and back, they were allowed to give any number of minutes as an answer, however most respondents gave an approximate answer like 15 or 30 min.

For the analysis the natural logarithm of distance will be used, since distances to the polling station are heavily right skewed. One minute will be added to all distances, because the log of 0 cannot be computed. This added minute should not change the end result and in case of 0 answers is probably closer to the truth.



Graph 1 - Distance to polling station (pooled data)

Technological factors - There are two main limiting factors in regard to technology - skills and use.

A person's skill with computers can be measured using their self-reported computer literacy. Respondents were asked "How do You evaluate Your computer skills? Are they: " and were given the options of "very good", "good", "average", "basic" and "no computer skills", they also

had the option to refuse or give a do-not-know answer. Refusals were almost nonexistent, with 4 cases on all years combined and although the question is somewhat vague, do-not-know answers make up less than a one percentage of all answers.

For measuring the usage of internet I suggest an index consisting of the frequency of internet use, how often (if ever) the internet is used for information gathering and how often (if ever) for communication. The exact same questions were asked each year.

The frequency of internet use was measured by asking respondents how many days over the last week they have used the internet. The answers to that question were re-calculated to a 4 point scale, since most respondents are either not using the internet or are frequent users, giving no reason to count 1-4 days or 5-6 days as separate categories. The final item measures the frequency of use in the last week as none, every other day, frequent and always.

Internet use for information gathering and communication was measured using identical items. Respondents were asked if they use the internet to look up information, with the options "Very often", "quite often", "rarely" and "never". The item about communication used the same structure, but provided examples of communication (i.e. send E-mail, use Skype).

To compute the index the frequency measured on the new scale (1-4), using the internet for looking up information and communication are added together. Notice that all items in the index use a 1 to 4 scale, which means they are all weighted equal in the final item. To bring the index to a more conventional 1-10 scale, 2 is subtracted from the value of the index.

Finally people who do not use the internet at all will be given an index value of zero. If someone does or does not use the internet will be determined by a separate preceding item asking exactly that question with yes or no answers. If any one of the questions in the index was not answered then the index will not be calculated for that person. The maximum number of missing cases was 10, which was in the study following 2009 European parliamentary election.

As such the index represents the use of internet with 0 being no use; 1 corresponds to a person who generally uses the internet, but not for information search or communication and did not

happen to use the internet last week; 10 indicating someone who does these things very often and who was online every day in the last week.

Using Cronbach's alpha to estimate the internal consistency of the index gives good results, values of alpha range from 0.61 (2011) to 0.77 (2007). This shows that the measurements are indeed reliable. Cronbach's alpha is most appropriately used when the items measure different substantive areas within a single construct (Dunn, Baguley & Brunsten, 2014), as is the case here, where items measure usage frequency for differing activities.

3.3. Model

The main focus of this thesis is the cost saving effect of I-voting, as such the main interest lies in mode selection. I-voters and paper ballot voters can be compared in order to find out what made them choose one mode over the other.

The sample has an equal share of online and regular voters for each year. The absolute number of I-voters or the absolute odds to I-vote instead of casting a paper ballot are meaningless, as they do not represent empirical patterns, but the way the sample was collected. Instead the variables of interest are compared to mode choice.

Logit models will be constructed to predict I-voting vs. casting a paper ballot among voters in each election with available data. The two main variables of interest will be the distance to the nearest polling station as an indicator for the cost of regular voting, and the self-reported skill with computers and the proposed index as a measure of technological aptitude.

The following table 1 gives an overview of what models will be constructed for testing the hypotheses.

Table 1: Expected results by hypothesis

Hypothesis	Equation	Condition
1. As the cost of conventional voting increases, the probability of I-voting increases.	$Y_i = \beta_0 + \beta_1 C_i + \beta_2 T_i + \beta_3 K_i + \varepsilon_i$	$\beta_1 > 0$
2. The increase of the probability of I-voting as a function of the increasing cost of conventional voting is conditional on the level of technological skills.	$Y_i = \beta_0 + \beta_1 C_i + \beta_2 T_i + \beta_3 K_i + \beta_4 C_i \times T_i + \varepsilon_i$	$\beta_4 \neq 0$
3. The predictive power of the technological factors decreases over time	$Y_{i,t_1} = \beta_0 + \beta_{1t_1} C_{i,t_1} + \beta_{2,t_1} T_{i,t_1} + \beta_{3t_1} K_{i,t_1} + \varepsilon_{i,t_1}$ $Y_{i,t_2} = \beta_0 + \beta_{2t_2} C_{i,t_2} + \beta_{2,t_2} T_{i,t_2} + \beta_{3t_2} K_{i,t_2} + \varepsilon_{i,t_2}$ $Y_{i,t_3} = \beta_0 + \beta_{3t_3} C_{i,t_3} + \beta_{2,t_3} T_{i,t_3} + \beta_{3t_3} K_{i,t_3} + \varepsilon_{i,t_3}$ $Y_{i,t_4} = \beta_0 + \beta_{4t_4} C_{i,t_4} + \beta_{2,t_4} T_{i,t_4} + \beta_{3t_4} K_{i,t_4} + \varepsilon_{i,t_4}$	β_{2,t_1} $> \beta_{2,t_2}$ $> \beta_{2,t_3}$ $> \beta_{2,t_4}$

Where C is the cost of regular voting, T represents technological factors (skills and index), K stands for a vector of control variables and t represents different points in time, i.e. different elections with available data. The first two hypothesis will be tested on pooled data and the third hypothesis will be tested by comparing models based on subsequent years.

There is a theoretical difference between skills with computers and frequency of internet use. Skill in using computers is part of skills access, while internet use is part of usage access. The two will not be conflated into a single variable in the models. This allows to discover a potential difference between a habit and a skill barrier, that might have otherwise been lost.

Multiple control variables will be included in the models, but only if their contribution is significant. Age and income will be included in each model. Income is the income decile of the respondent based on self-reported income. Age has a significant but very low impact on some years and no significant impact to others. Gender, urban or rural residence and education was also controlled for, but none had a significant impact on I-voting and did not increase the predictive power of models.

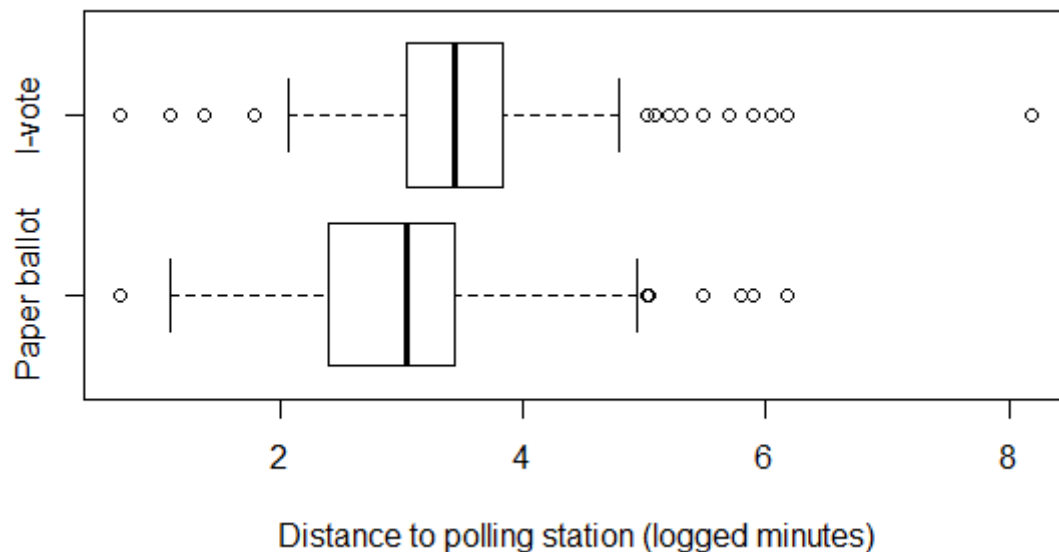
According to Aldrich (1993) one should expect large errors in turnout models, because low-cost and low benefit decisions are volatile, minor changes can bring about large changes in the results. As a consequence, the models presented here are expected to have large errors.

4. Empirical findings

4.1. Descriptive statistics

The main continuous variables in subsequent models will be the logged distance to the polling station and the index of internet use. Comparing their values for I-voters and regular voters will help to give an idea of the data structure.

The difference between distance values for I-voters and regular voters is fairly small, but significant. The mean for regular voters is 3.01 (around 20 minutes) and for I-voters is 3.40 (around half an hour), 95% confidence interval for the difference is 0.45 to 0.34. A box and whisker diagram illustrates the result (see Graph 2).



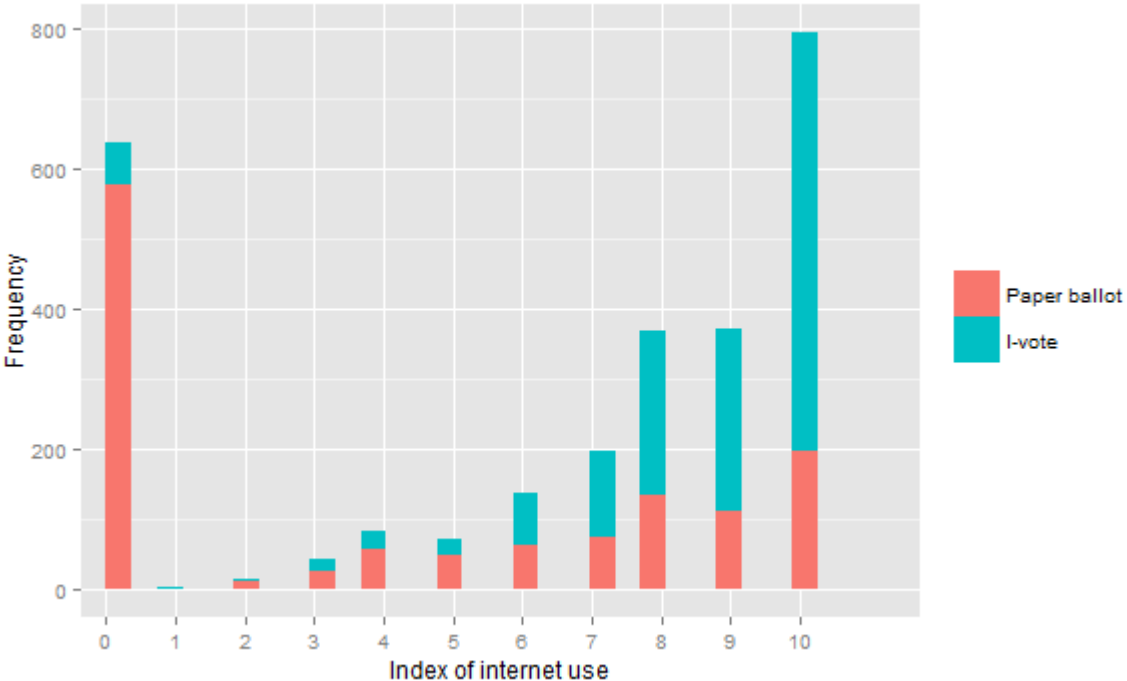
Graph 2 - box and whiskers diagram comparing mode choice and distance to polling station (pooled data)

There is less variation among I-voters, who tend to live slightly further from polling stations. Most extreme outliers of distance are among I-voters. Three quarters of I-voters live further away than the median regular voter.

To get an idea of how much a reduction in cost might affect turnout, one can compare I-voters who claim that they would have voted anyway if there would have been no option to vote online and I-voters who reported, that they would have abstained.

In the chosen sample 13.6 % of I-voters reported that they would have abstained, had I-voting not been an option. Their distance to the polling station can be compared to those who reported, that they would have voted anyway. The possible abstainers should have a larger distance to the polling station (higher costs of regular voting).

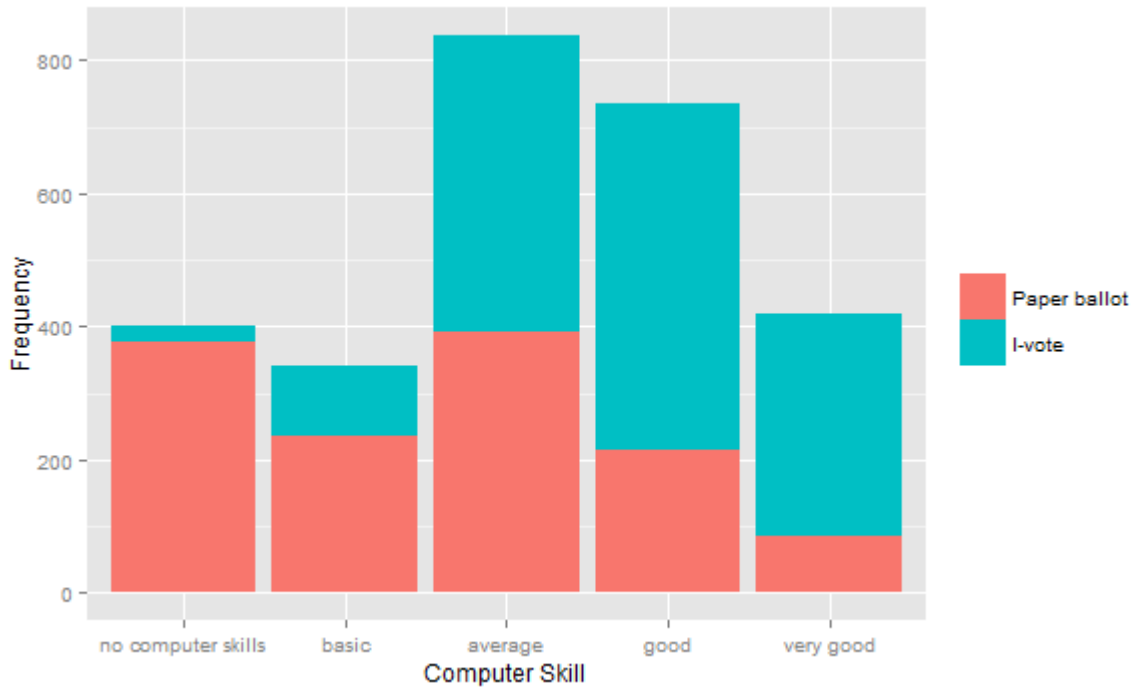
The mean logged distance for would be abstainers is 3.72 (around 40 minutes) and 3.35 (around 26 minutes) for voters. 95% confidence interval for the differences in means is 0.22 to 0.51. The difference is as expected although quite small. The effect size is acceptable, because a reduction in cost should only change the decision for those whose gain from voting nearly matches their cost of voting, one should expect this to be a minority at any one time.



Graph 3 - Distribution of index values among voters (pooled data)

The index of internet use is unevenly distributed (see Graph 3). There is a large and obvious difference between the index values of I-voters and regular voters. Regular voters have an average index value of 4.24 and I-voters 8.29, 95% confidence interval for the difference is 4.30 to 3.80. The usage of internet has a large role to play in mode selection. However there are I-voters for every available index value, i.e. even people claiming not to use the internet have voted

online (the sample includes 60 such instances). Although the index is a very strong predictor, it is not an absolute predictor.



Graph 4 - Computer skill among voters (pooled data)

Sample includes a roughly equal share of both regular voters and paper ballot voters, who are unevenly divided among different categories of computer skill (see Graph 4). There are I-voters among all different categories of computer skill, even among 'no computer skills'. Average computer skills is a good point of comparison, with roughly half being I-voters. 'Good' and 'very good' computer skills' are more common among I-voters, while very few I-voters claim no or only basic computer skills.

4.2. Cost of voting

In order to test the first hypothesis, a logistic regression model will be estimated using pooled data from 2007 to 2011 (see Table 2).

**Table 2: Impact of cost on I-voting
(logistic regression estimates, pooled data)**

Predictor	Odds ratio (std. error)	
(Intercept)	0.00 (0.00)	***
Computer skills (base: 'Average')		
'No computer skills'	0.20 (0.06)	***
'Basic'	0.79 (0.14)	
'Good'	1.48 (0.19)	**
'Very good'	2.01 (0.36)	***
Index	1.26 (0.03)	***
Distance	3.22 (0.26)	***
Income deciles	1.12 (0.02)	***
Age	1 0	
<hr/>		
AIC	2339.01	
BIC	2391.34	
Log Likelihood	-1160.51	
Deviance	2321.01	
Num. obs.	2474	
Nagelkerke pseudo R ²	0.42	
<hr/>		
*** p<0.001 **p<0.01 *p<0.05		

The model has reasonably large predictive power with the Nagelkerke pseudo R square being 0.42. The first hypothesis is clearly confirmed, in every election there is a clear relationship

between the distance to the polling station and chance of I-voting. The odds of voting online increase between 2.7-3.8 times (95% confidence interval) for every one point increase in the logged distance to the polling station. For example the odds of voting online are three times larger for someone who lives 15 minutes from a polling station than for someone who lives 5 minutes away.

4.3. Technological factors

To test the second hypothesis model 2 will be run using pooled data from 2007 to 2011, it is identical to the first model, but includes interaction terms (see Table 3).

All interaction terms are not significant. The effect of distance does not seem to depend on technological factors. Because of this the interaction terms will be dropped from further analysis. Technological factors themselves however have a strong connection to I-voting.

Different categories of PC users are somewhat distinguishable. While individual differences between different categories cannot be confirmed, the higher level computer users are significantly more likely to vote online. Both 'good' and 'very good' PC users are significantly more likely to vote online than 'average' users, meanwhile respondents claiming to have no computer skills are far less likely to vote online.

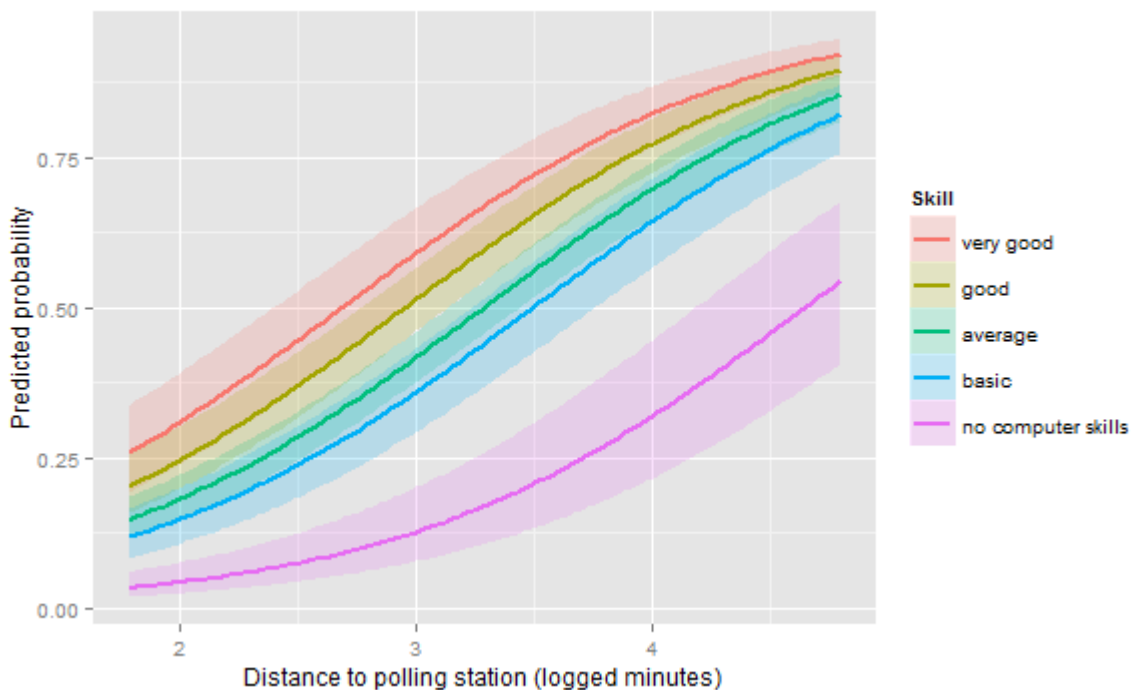
The index of internet use predicts I-voting, with people scoring higher on the index also being more likely to vote online. With every point of increase in the index the odds of someone voting online instead of casting a paper ballot increase 1.2-1.3 times (95% confidence interval) on average. This does not seem large at first, but the effect is sizable over the amount of available index values. For example someone with an index value of 10 is between five to ten times more likely to vote online than someone with an index value of 1.

Table 3 Impact of technological factors on I-voting (logistic regression estimates, pooled data with interaction)

Predictor	Odds ratio (std. error)	
(Intercept)	0.007828 (0.01)	
Computer skills (contrast: 'Average')		
'No computer skills'	0.05 (0.08)	*
'Basic'	0.61 (0.57)	
'Good'	0.64 (0.43)	
'Very good'	2.83 (2.15)	
Index	1.15 (0.13)	
Distance	2.44 (0.66)	**
Income deciles	1.12 (0.02)	***
Age	1 0	
Index*Distance	1.03 (0.03)	
'No skills' * Distance	1.49 (0.58)	
'Basic' * Distance	1.08 (0.30)	
'Good' * Distance	1.31 (0.28)	
'Very good' * Distance	0.90 (0.22)	
AIC	2345.3	
BIC	2426.69	
Log Likelihood	-1158.65	
Deviance	2317.3	
Num. obs.	2474	
Nagelkerke pseudo R ²	0.48	

*** p<0.001 **p<0.01 *p<0.05

To show the effect of distance the model wise predicted probabilities will be graphed against the logged distance to the polling station, keeping all other variables constant at their mean value. Different levels of PC literacy can be graphed separately to show how the increase in probability is related to skill in computer use.



Graph 5 - Predicted probability to vote online (pooled model)

On a distance from 5 to 60 min (2 to 4), which houses most of the data, there is a clear rise in the probability to I-vote as distance increases, regardless of PC skills. Distance to the polling station seems to have the same effect on all levels of PC users (predicted probability lines are nearly parallel). What makes the different categories distinguishable is the likelihood of I-voting, where better PC users are always more likely to use the option than lower level users. The differences are fairly constant in the interval of 5 to 60 minutes.

The findings fit well with the assumption, that I-voting decreases costs and becomes a more preferable option the larger those costs are. Skills in using PCs does not seem to be a problem, when trying to use I-voting, there is no marked drop in effect size between different categories of users.

There is however a difference between the likelihood of casting a vote online in the first place, between different levels of computer users. A larger need, in the form of a larger distance to the polling station, does not eliminate the difference. People more skilled with using computers start with a higher chance to vote online, even if the distance to the polling station is small.

4.4. Time effects

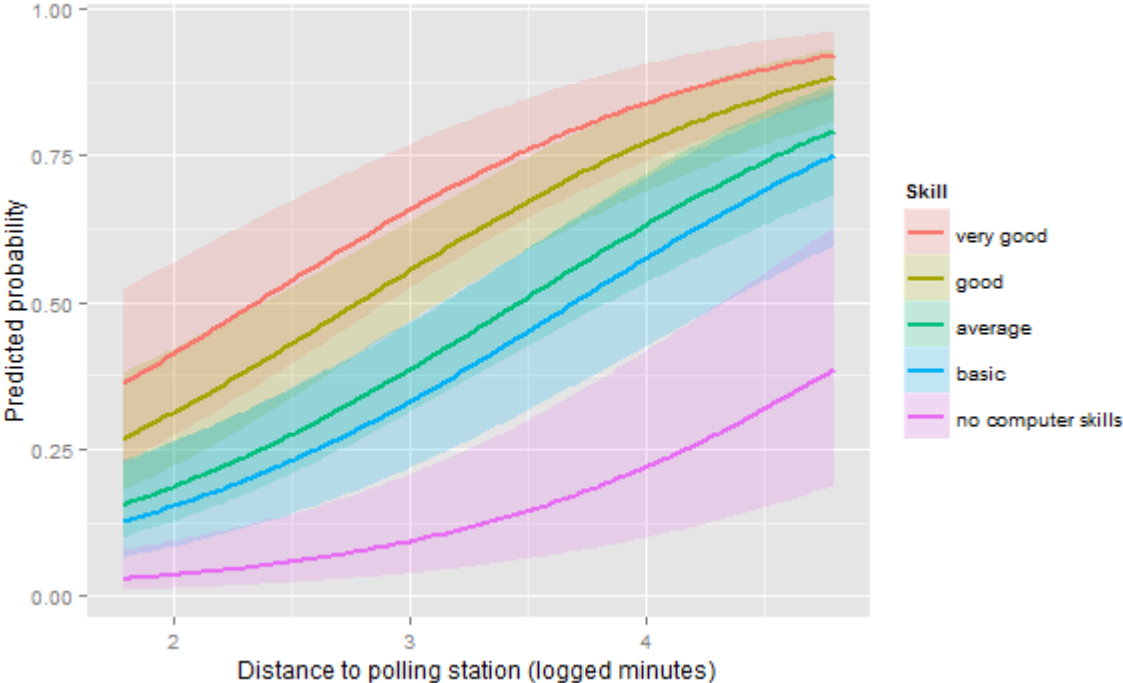
To test the final hypothesis about whether the effect of technological factors decreases over time, analogous models will be run separately for all years with available data (see Table 4).

Table 4: Model comparison by election

Predictor	2007 National		2009 European Parliament		2009 Local		2011 National	
	Odds ratio	(std. error)	Odds ratio	(std. error)	Odds ratio	(std. error)	Odds ratio	(std. error)
(Intercept)	0.00	*** (0.00)	0.00	*** (0.00)	0.00	*** (0.00)	0.02	*** (0.01)
Computer skills (contrast: 'Average')								
'No computer skills'	0.16	*** (0.09)	0.08	*** (0.06)	0.13	** (0.10)	0.79	 (0.47)
'Basic'	0.79	 (0.27)	0.54	 (0.20)	1.03	 (0.41)	0.81	 (0.32)
'Good'	1.99	** (0.46)	1.03	 (0.28)	1.68	 (0.47)	1.12	 (0.32)
'Very good'	3.06	*** (0.95)	1.82	 (0.71)	2.29	* (0.89)	1.19	 (0.45)
Index	1.25	*** (0.05)	1.26	*** (0.06)	1.30	*** (0.08)	1.30	*** (0.06)
Distance	2.72	*** (0.38)	4.14	*** (0.74)	4.85	*** (0.92)	2.32	*** (0.39)
Income deciles	1.09	** (0.04)	1.12	** (0.04)	1.08	 (0.04)	1.15	*** (0.03)
Age	1.03	*** (0.01)	1.00	 (0.01)	0.99	 (0.01)	0.98	* (0.01)
AIC	741.41		547.88		503.35		542.73	
BIC	782.69		587.42		542.53		581.95	
Log Likelihood	-361.71		-264.94		-242.68		-262.36	
Deviance	723.41		529.88		485.35		524.73	
Num. obs.	725		598		574		577	
Nagelkerke pseudo R ²	0.43		0.51		0.55		0.51	

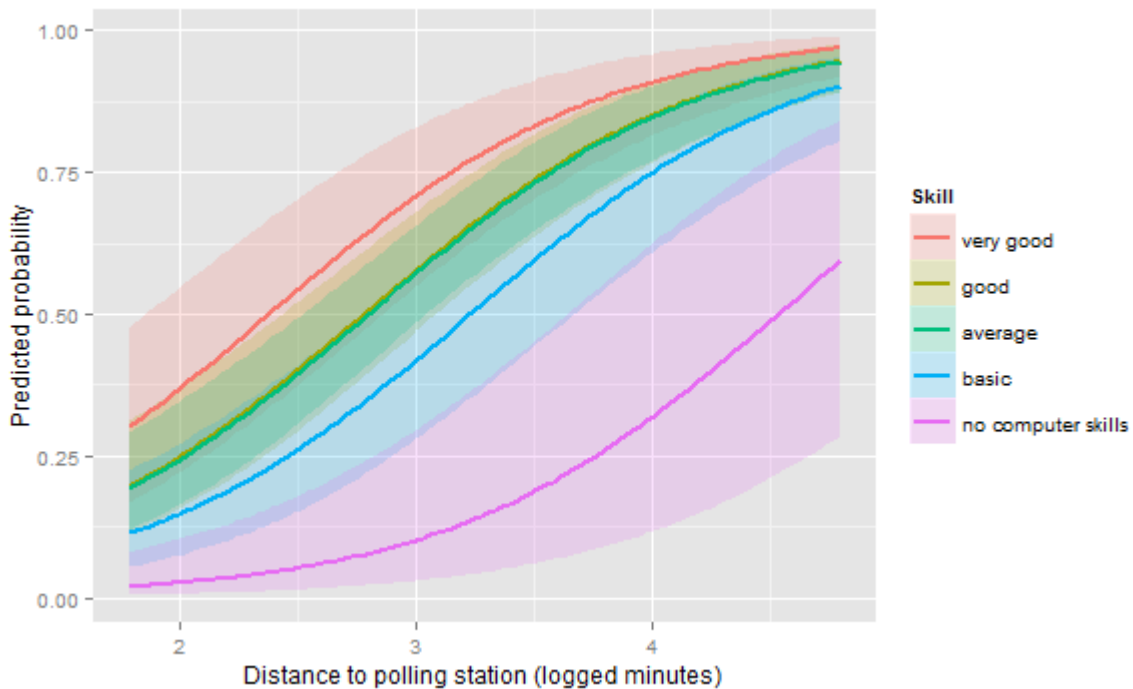
*** p<0.001 **p<0.01 *p<0.05

The effect of the index is stable and has no significant variation over the years, unlike computer skills. To get a better overview of the effect of computer skills it is reasonable to graph the models predicted probabilities for different categories of computer skill over the values of distance (keeping other variables constant at their mean).



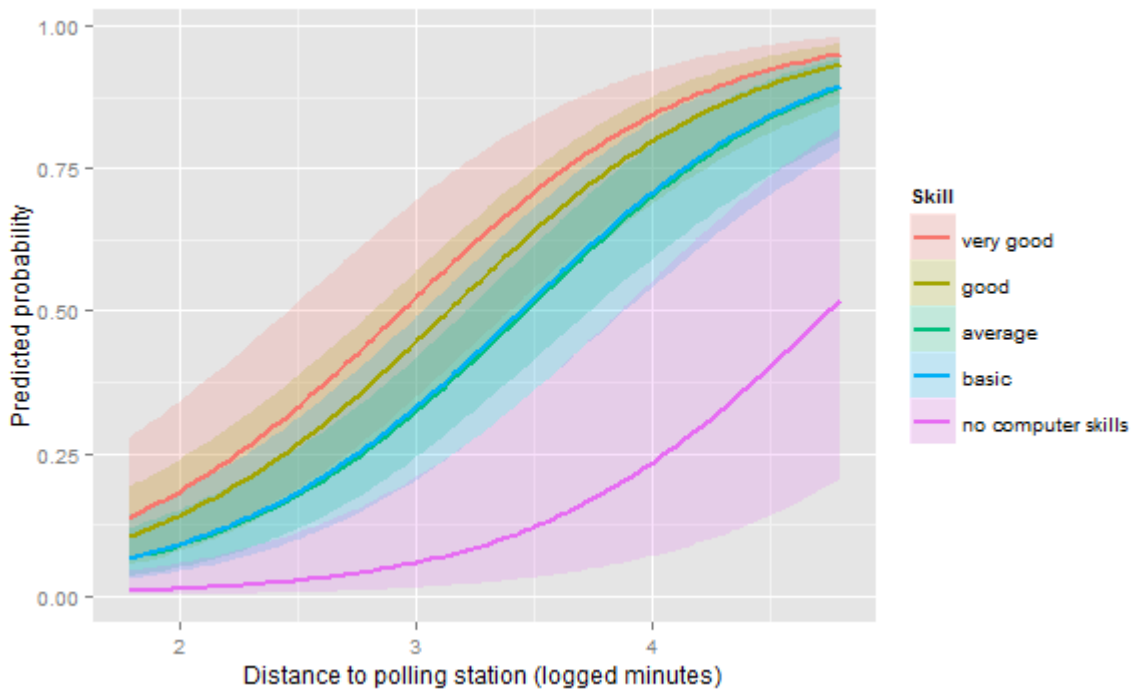
Graph 6 - Predicted probability to vote online (2007)

In 2007 different categories of PC users are somewhat distinguishable. A difference between "very good" and "good" cannot be confirmed, the difference between the first two categories and "average" or "basic" is statistically insignificant. However highest categories are still different from lowest, very good computer users are reliably more likely to vote online than basic users.



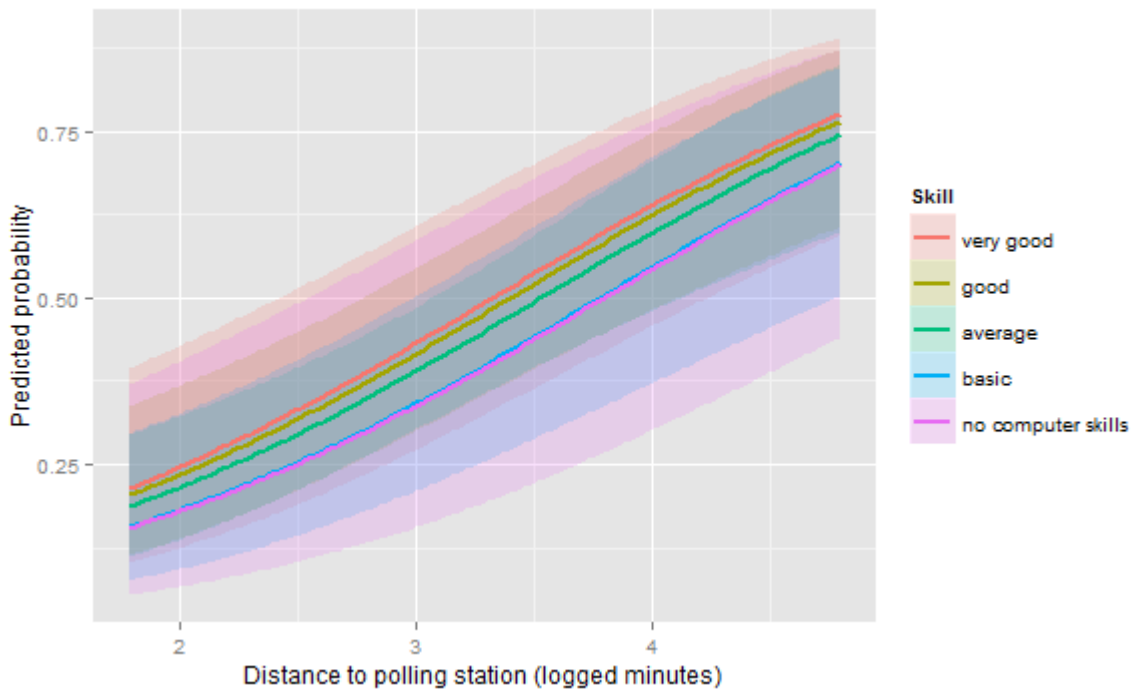
Graph 7 - Predicted probability to vote online (2009 EP)

In 2009 European parliamentary elections the results are much the same. According to the hypothesis technological factors should lose their impact over time, which translates to non-reliable differences among different levels of computer users. Although confidence intervals overlap, as in 2007, the highest level users are still more likely to vote online. Except the merger of good and average users, the ordering of the categories remains intact.



Graph 8 - Predicted probability to vote online (2009 L)

2009 local elections are in most part similar to European Parliament elections the slightly smaller differences between the skilled categories. The difference is probably related to the differing electorate of these elections. Although neighboring categories of computer users are not significantly different, PC skills is still a good predictor of I-voting, as higher categories have a higher odds to vote online than lower categories (except 'average' and 'basic'). Very good computer skills are reliably different from average ones, however the size of the difference is small.



Graph 9 - Predicted probability to vote online (2011)

The 2011 national elections present the first case when elections of the same level can be compared, in this case with the 2007 national election. The effect of distance has slightly increased, compared to 2007, however the difference is within the 95% confidence intervals. Curiously the effect of distance was larger during both 2009 elections than in national elections.

Computer skills has become completely unreliable in predicting I-voting. At the same time however the predictive power of the index has remained the same as in 2007.

I-voting has dispersed between different skill levels of computer users, the lower levels have 'caught up'. At the same time less frequent internet users are still less likely to vote online. This does indicate that the skill barrier disappears but usage barrier remains, however the model leaves a lot of room for error in regard to computer skills (diagnostics are discussed in detail below). This result should be considered inconclusive in regards to skill.

The total number of I-voters has greatly increased from 5.5% of all votes cast in 2007 to 24.3% of all votes in 2011 (National Electoral Committee, 2015). More frequent internet users were

more likely to vote online in 2007 as much as in 2011. The increase of I-voters has not come from less frequent internet users adopting the technology. Instead I-voting has become more popular among all levels of internet users, keeping differences intact.

The third hypothesis is not confirmed, the effect of technological factors does not decrease over time, with the exception of computer skills in 2011.

4.5. Model diagnostics and limitations

4.5.1. Sample problems

The available sample has a few problems, mainly for comparing different elections to each other.

The different categories of computer skills are unevenly distributed among the subsamples of I-voters in each year. This does not represent a large problem with pooled data, but yearly models suffer from low subsamples. The 2007 sample included 8 people who claimed to have no skill with computers who voted online, other samples have between 3-8 cases in the same category. Basic PC skilled people amongst I-voters are also lacking, however not as severely. Results for the poorest level PC literacy should be taken with a grain of salt.

Special consideration needs to be given to the more extreme values of distance, in these cases model predictions cannot be taken at face value. In 2007 the lowest distance with a considerable amount of voters in the sample (38) is 1.791 (corresponds to the answer 5 minutes in the survey). Model predictions for lower values (only 4 voters in the sample) should not be considered. Similarly there are only a few values (11) above 4.795 (corresponds to the answer 2 hours in the survey).

4.5.2. Model diagnostics

PC skills and the index of internet use are correlated, with more PC literate people scoring higher on the index in general and the category "no computer skills" scoring 0 on the index in most cases. This is true for all elections with available data.

Multicollinearity could destabilize the model (Field, Miles & Zoë, 2012: 274-276), as a diagnostic the tolerance is computed for each variable in each model. Menard (1995) suggests that values below 0.2 are problematic. For pooled data all tolerance values are above 0.49. Models for individual years all have tolerance values consistently above 0.3 for all variables, indicating no large problem of multicollinearity.

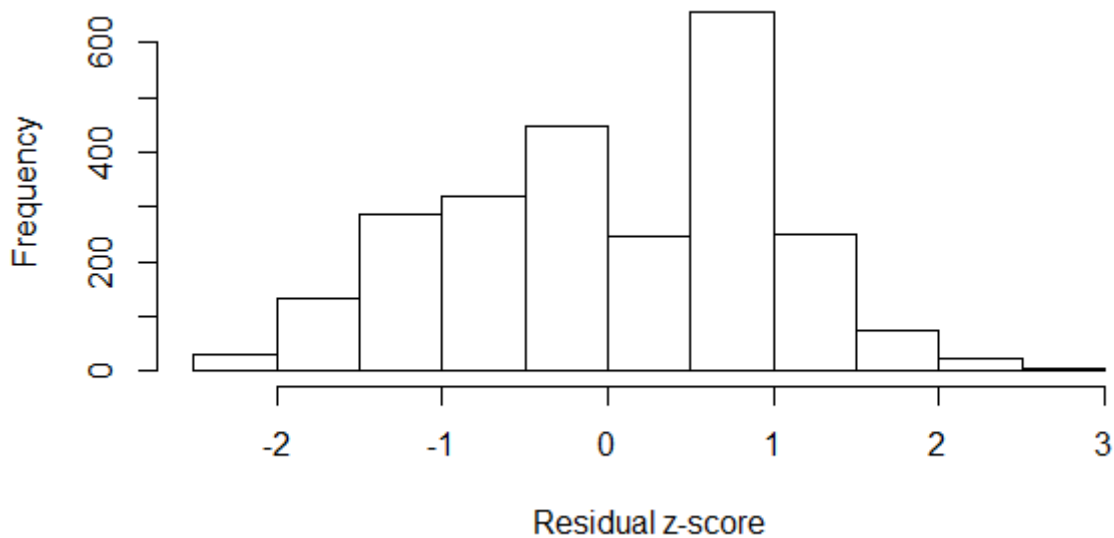
In order to test that each continuous predictor is linearly related to the log of the outcome variable alternative models were run that included the interaction of the predictor and the log of itself (Field, Miles & Zoë, 2012: 344). None of these interactions were significant, except age. The non-linear effect of age was taken into account in the formula.

4.5.3. Model residuals

Two steps need to be taken in regard to residuals - first points where the model fits poorly should be isolated and second cases with an undue amount of influence should be identified (Field, Miles & Zoë, 2012: 340).

Standardized residuals (z-scores) are used to detect outliers. Z-score cutoff points can be assigned based on known values for a normally distributed sample, for example 95% of z-scores should lie between -1.96 to 1.96 (Field, Miles & Zoë, 2012: 269).

In the model with pooled data residuals are not normally distributed. The largest residual for the pooled model is 2.96, which does not warrant special attention. 95% of scores are well within +/- 1.96. The model is not suffering from extreme outliers, but the distribution of residuals makes the predictions somewhat suspect.



Graph 10 - Residuals (pooled model)

Leverage or hat values, gauge influence of observed value of the outcome variable over the predicted values. In case no cases have an undue influence on the model, all leverage values should be near the average of $((k+1)/n)$, where k is the number of predictors and n is sample size (Field, Miles & Zoë, 2012: 269-270). Three times larger than average values are cause for concern (Stevens, 2002). There are a large number of cases (9%) which leverage value is larger than thrice the expected.

To test how much influence certain cases have on model predictions the models will be run with that case and without, the difference between the values for each predictor can thus be examined, these values are sometimes known as DFBeta (Field, Miles & Zoë, 2012: 270). For the majority of cases this value will be zero or close to zero. The maximum values will indicate if there is reason for concern, i.e. if one case seriously affects the predictions.

In the model with pooled data no cases have a substantial impact on any coefficients.

Time models have an additional complication, the smaller sample size for models based on one election year data makes them more susceptible to the influence of a few cases. These models will all be examined separately for both outliers and influential cases.

In 2007 there are multiple cases (8%) where leverage exceeds the average more than three times, with the maximum being more than 6 times larger. However the model coefficients do not change much from their inclusion. In 2007 'No computer skills' has a maximum DFBeta value of 0.11 (the existence of one case lowers the prediction), which is to be expected, with less than 10 cases omitting any one case could change the predictions. In the category 'Basic computer skills' the predictor can change by up to 0.07 from the removal of a case, which is not substantial, as the coefficient is -1.02, other DFBeta values are even smaller.

In 2009 European parliamentary elections standardized residuals are within expected limits, but are not normally distributed, being right skewed. Approximately 10% of the cases have a leverage value that is three or more times larger than the expected value. Those cases do not change the coefficients for the variables of interest by a considerable amount, DFBeta values indicate that no coefficients change considerably from the removal of any case.

In 2009 local elections standardized residuals are within expected limits and are nearly normally distributed. Approximately 10% of the cases have a leverage value that is three or more times larger than the expected value. There are two very influential cases, they both have extreme values of distance, 5 hours and 5 and a half hours, both have an index value of 0, no computer skills and one of them voted online, the other did not. The last case has enough influence to single handedly change the coefficient for the 'no computer skills' category by more than a tenth.

DFBeta values indicate a slight variation in coefficients, with the exception of 'no computer skills', no coefficients change by a tenth or more from the removal of any case.

In 2011 standardized residuals are within expected limits and are not normally distributed. Approximately 10% of the cases have a leverage value that is three or more times larger than the expected value. DFBeta values indicate no substantial change in the coefficients from the removal of any one case.

Predictions for the lower categories of computer skill are problematic, as they depend too much on a few cases. The observed fluctuations in the predictive power of skill categories might in fact be random noise. As such it is ill advised to attribute too much meaning to them.

4.6. Sample selection bias

Only people who have decided to vote will make the choice between different modes of voting. A situation where the final outcome is observable only when a previous condition is met creates a sample selection problem (Heckman, 1979).

There are two dependent choices, voting or abstaining and I-voting or using a paper ballot. The second choice is only observable if the citizen decides to vote in the first place. Both of these can be modeled with an equation, where the result of the second equation is observable based on the result of the first equation - the result of mode choice is only observable if the result of the first equation is voting.

If some or several unobserved variables lead to both voting and I-voting, the estimates of the second equation will be biased, as part of the sample is selected because it has large error terms (the effect of the unobserved variable), the effects of variables of interest will then be underestimated. Note that there is no problem when the unmeasured variables affecting the selection equation are uncorrelated with the unmeasured variables affecting the outcome equation.

Estimation models, often called Heckman models, help to alleviate the problem by allowing simultaneous estimation of both outcome and selection (Toomet & Henningsen, 2008).

The estimation requires an additional variable as an exclusion restriction (Sartori, 2003). For a restriction variable one seeks a variable that generates non-trivial variation in the selection variable (choice to vote), but a does not affect the outcome variable (voting mode selection) directly (Cameron & Trivedi, 2009: 558).

According to Downs (1957), one of the main reasons to vote is the difference to a person's utility based on who wins the elections. If someone is fairly neutral to the choices, their gain from casting a vote is smaller than someone's who has strong preferences. There is no reason why someone's perceived gain from voting should affect the choice of voting mode, making this an ideal restriction variable.

4.6.1. Using utility as an exclusion restriction

A score of for the utility of voting choices will be computed for each respondent. Each respondent was asked the question "There are many parties in Estonia which would like to have your vote. How probable is it that you will ever vote for the following parties?" and had to assign a score of 0 ("Is not at all probable") to 10 ("Very probable") to every party running in the election.

For the utility of voting versus abstaining it is not important if a person prefers one party or is opposed to one party. It is rational to vote for a favorable party and it is rational to vote "against" an unfavorable party by picking between neutral options. The rational citizen will derive some utility from voting if there is any variation in preference at all. This utility will be larger if there is more variation in their party preferences.

For modeling the utility of choices for a single individual the standard deviation of all party preferences is a natural choice. Thus only the dissimilarity of options affects the utility of choices. Equally bad or equally good options will not be counted as an incentive to vote.

However this approach has problems with missing values. Since preferences for different parties are sometimes incomplete (unknown for some parties), standard deviation can be misleading. For example a strong preference for one party and missing answers for the rest would indicate clear difference in utility, however would yield no standard deviation. Luckily such cases are rare, missing values are usually missing across the board. Such cases are interpreted as complete neutrality.

To judge the usefulness of standard deviation based utility as an exclusion restriction, its effect on turnout and mode choice will be compared. Utility of voting choices is roughly normally distributed, with the exception of a large amount of 0 values (complete neutrality). Utility is slightly higher among voters than abstainers (see Table 5), but the same among I-voters and regular voters (see Table 6).

Table 5: Mean utility of voting choices

	Abstained	Voted	
2009 European parliament	2.62	3.00	*
2009 Local	2.70	3.00	*
2011 National	2.70	3.30	*

*p < 0.05

Table 6: Mean utility of voting choices (by mode)

	Paper ballot	I-vote
2009 European parliament	2.95	3.00
2009 Local	3.02	2.96
2011 National	3.31	3.30

*p < 0.05

-Data for 2007 is not available, sample selection bias is not controlled for.

Another alternative is to create a logit model for voting vs. abstaining and I-voting vs. paper ballot using utility. Utility should positively contribute to the model of turnout and not have a significant effect in the case of mode selection. Simple logistic regression are run for both turnout and mode selection. Utility has a significant impact on turnout in every election with available data. As expected, the effect is not present when predicting the mode of voting. Pseudo R squares illustrate the find (see Table 7), although not high for turnout, they are around ten times smaller at best (essentially nonexistent) for mode selection. This confirms that utility affects turnout without affecting mode selection.

Table 7: Nagelkerke pseudo R squared comparison

	Turnout	Mode selection
2009 European parliament	.035	.001
2009 Local	.024	.002
2011 National	.088	.000

4.6.2. Selection models

Following Toomet and Henningsen (2008) Y_1 denotes if a person votes and Y_2 marks the mode choice. Y_2 is only observable if $Y_1=1$, as mode choice can only exist for voters. Y_1^* notes the realization for the latent value for selection 'tendency' and Y_2^* the outcome, thus we observe the selection (vote or abstain):

$$Y_1 = \begin{cases} 0 & \text{if } Y_1^* < 0 \\ 1 & \text{otherwise} \end{cases}$$

and the outcome (I-vote or paper ballot):

$$Y_2 = \begin{cases} - & \text{if } Y_1 = 0 \\ Y_2^* & \text{otherwise} \end{cases}$$

Two equations will be simultaneously estimated. The selection equation (vote or abstain):

$$Y_{1,i}^* = \beta_0 + \beta_1 C_i + \beta_2 T_i + \beta_3 K_i + \beta_4 U_i + \varepsilon_i$$

and the outcome equation (I-vote or paper ballot):

$$Y_{2,i}^* = \beta_0 + \beta_1 C_i + \beta_2 T_i + \beta_3 K_i + \varepsilon_i$$

Where C is the cost of regular voting, T represents technological factors (skills and index), K stands for a vector of control variables and U stands for utility of choices. Both equations are identical except for the inclusion of utility in the selection equation.

Selection models will be run using R's `sampleSelection` package, which uses maximum likelihood estimation based on initial values provided by two step estimation (Toomet & Henningsen, 2008). As an exception the model on 2009 local elections will use initial values provided by the SANN maximizer to overcome a robustness issue. Heckman style models will be run for both pooled data and by election data.

If there is a significant correlation in the error terms of the selection and outcome equation (Rho value), then there is a selection bias. No such correlation was found for any year. If selection does not bias results, one should see that the coefficients of the outcome equation match coefficients of normal probit regression (probit will be used since Heckman models cannot be run with logistic regressions, results are similar), a comparison of coefficients is provided (see Table 8).

The coefficients for the variables are very similar, only 2009 Local election show different coefficients, indicating that regular models might slightly over rate the effects of technological factors. There is no large enough selection bias for it to significantly alter the results.

Table 8: Comparison of regular probit models and selection models outcome equation

	Pooled model		Outcome (pooled)		2009 European parliament		Outcome (2009 EP)		2009 Local		Outcome (2009 L)		2011		Outcome (2011)	
(Intercept)	-3.39	***	-3.58	***	-3.46	***	-3.42	*	-3.94	***	-1.56	**	-2.44	***	-2.8	***
	(0.23)		(0.36)		(0.51)		(1.34)		(0.54)		(0.47)		(0.49)		(0.57)	
'No computer skills'	-0.83	***	-0.7	***	-1.37	***	-1.18	*	-1.04	**	-0.22		-0.06		-0.11	
	(0.16)		(0.20)		(0.38)		(0.60)		(0.40)		(0.25)		(0.32)		(0.33)	
'Basic'	-0.15		-0.12		-0.38		-0.29		-0.03		0		-0.12		-0.14	
	(0.11)		(0.13)		(0.22)		(0.21)		(0.23)		(0.21)		(0.23)		(0.22)	
'Good'	0.24	**	0.19	.	0.04		0.01		0.31		0.27		0.07		0.19	
	(0.08)		(0.10)		(0.16)		(0.17)		(0.16)		(0.18)		(0.17)		(0.19)	
'Very good'	0.41	***	0.27	*	0.34		0.26		0.47	*	0.34		0.11		0.21	
	(0.10)		(0.12)		(0.22)		(0.22)		(0.22)		(0.26)		(0.22)		(0.23)	
Index	0.14	***	0.15	***	0.14	***	0.14	***	0.15	***	0.12	***	0.16	***	0.16	***
	(0.01)		(0.02)		(0.03)		(0.04)		(0.03)		(0.03)		(0.03)		(0.03)	
Distance	0.68	***	0.68	***	0.83	***	0.85	***	0.9	***	0.54	***	0.47	***	0.41	***
	(0.05)		(0.01)		(0.10)		(0.11)		(0.10)		(0.10)		(0.10)		(0.11)	
Income deciles	0.07	***	0.07	***	0.06	*	0.06	*	0.05	*	0.04	.	0.09	***	0.09	***
	(0.01)		(0.01)		(0.02)		(0.03)		(0.02)		(0.02)		(0.02)		0.02	
Age	0		0		0		0		-0.01		0		-0.01	*	0	
	0		(0.01)		(0.01)		0.01		(0.01)		0		(0.01)		(0.01)	
Rho			0.37				-0.04				0.17				0.51	
Std. error			(0.41)				(1.05)				(0.11)				(0.44)	

*** p<0.001 **p<0.01 *p<0.05

5. Discussion

Distance to the polling station has a clear positive effect on the probability to I-vote instead of voting by paper ballot, although the effect varies somewhat between elections, it is still reasonably stable over time - it does not disappear in later elections. Also of note, distance seems to affect different types of computer users very similarly. Models predict a fairly large effect of distance, while I-voters and regular voters are not very dissimilar in regards to distance.

The effect of distance to odds of I-voting was already studied by Solvak, Vassil & Vinkel (2014), albeit using somewhat different control variables and not considering change over time. The results still match.

At first it seems like confirming the obvious: people living far away from a polling station would rather vote from home than go there. This gives us however a clear indication of rationality in the voting process, the results look like people are using cost minimizing modes of voting. One vote cast has an equal amount of utility regardless of mode choice, thus a rational actor would choose the cost minimizing mode *ceteris paribus*.

We do not actually know how much different voters value their time or effort, thus we can only make broad generalizations about the cost of voting options. For example, the cost of 10 minutes is not directly comparable to the cost of voting online, for some people it might be easier to sacrifice ten minutes, for others it might be voting online. Even assuming completely rational actors the effect of distance should be incomplete in predicting I-voting.

The first hypothesis is confirmed: An increase in the conventional cost of voting increases the probability to I-vote. This means that I-voting has the potential to lower the cost of voting for some and thus increase turnout by the amount of people who were near the 'tipping point'. The total size of this effect should be minor, after all the cost of the voting act itself is a smaller part of the total cost of voting. Self-reported intentions indicate that around 13% of I-voters would abstain if I-voting was not possible.

An index of internet use was computed using the number of days during the last week in which the respondent had used the internet and how often they use the internet for looking up

information or communication. This index performs well in predicting the mode of voting, people with higher index values are more likely to vote online.

The index was designed to measure usage as a form of the digital divide, the results fit well with Van Dijk's (2005) theory - frequent users of the previous technology are likely to adopt the next step.

There was no significant interaction between the index and distance. The effect was not conditional on the level of internet use. This means that people who live far from a polling station and were not internet users were not less likely to vote online than regular users, when initial difference is taken into account.

As a measure of skill the self-reported level of PC skills was used to predict online voting. Results using this variable are not as reliable, since those models suffered from low sub-samples. Similarly to the index, the different levels of computer skill did differ in their likelihood to vote online. Although the difference between the levels was not always clear, the ordering remained intact until 2011.

When the effect of distance is used in conjunction with computer skills, there appeared to be very little variance between different types of PC users. The likelihood to vote online of all categories of PC users increased with distance. Essentially the effect of distance is not conditional on the level of PC skills.

The second hypothesis is not confirmed: the increase in the probability to I-vote (as a function of increasing costs of conventional voting) is not conditional of use of internet or skills with computers. The effect increased costs seem to have is roughly equal regardless of technological factors. This result implies that the technological barrier is not a major hindrance to using I-voting. More technology savvy people will more likely start I-voting, but when there is a large enough need even the least adept can vote online.

The predictive power of the index did not change significantly over the time period of 2007 to 2011. The third hypothesis is not confirmed - the predictive power of technological factors does not decrease over time.

If Van Dijk's (2005) stratification model of technological adoption holds true, one should be able to observe constant differences between different levels of technology users. In this case the difference of the probability to I-vote between different levels of technology users should remain constant. Which is the obtained result, different levels of skill with computers managed to predict I-voting up to 2011 and the index of internet use throughout the period. This raises the question, where do the additional I-voters come from?

The stratification model can explain the issue. Since diffusion is still taking place in all subgroups of the population, the total number of I-voters can increase. The total number of I-voters has increased five times during the time span of available data. Yet a random selection of them indicates little difference in technological aptitude of neither I-voters or paper ballot voters compared to previous elections. A reasonable conclusion could be that the number of I-voters increased among all levels of technology users.

This means, that the rate of adoption between different categories of technological aptitude is very similar. Previous familiarity with internet or computers is not a problem for adopting I-voting.

Finally a few conclusions in the context of rational choice are presented. The assumption that people will choose the less costly voting method is confirmed. It is impossible to directly observe the less costly alternative being chosen, since the costs of casting a paper ballot and the costs of online voting cannot be directly compared. However the clear pattern between them suggests that larger costs of regular voting force people to vote online. Thus the first conclusion:

1. People will choose the less costly mode of casting a vote.

The different initial probabilities of voting online between different levels of technology users suggest a base cost of online voting that is dependent on previous familiarity with computers and the internet, which fits well with the stratification model of technological adoption. The second conclusion is:

2. The individual cost of voting online depends on previous familiarity with computers and the internet.

Finally, since the observed relationships do not change, but the total number of I-voters does, the cost of I-voting has to decrease over time, to make it a more preferable option (cost of regular voting remains constant, because the method to cast a vote has not changed).

3. Cost of voting online decreases over time.

From these concludes that I-voting can raise turnout by providing a lower cost method of participation. However initially I-voting is a less costly alternative only to a minority and thus has little impact on turnout.

6. Summary

The aim of this thesis was to evaluate if technological limitations prevent I-voting from having a positive effect on turnout. Among other positive characteristics I-voting was hoped to provide a more convenient method of casting a vote, which might have positive effect on turnout. Initial results from adopting nations did not confirm this, however empirical evidence has been few and wide between. Only recently has the Estonian case made it possible to observe nationwide I-voting over a longer period of time.

I-voting has been available in Estonia since 2005, usage was small at first with less than 2% of votes being cast online, but climbed fast and was around a third of all votes in 2015. Total turnout in these elections was slightly higher than in previous elections of the same level, but the effect I-voting had cannot be separated from normal fluctuations in turnout (Vassil, 2013).

Rational choice was used as a theoretical framework. The rational voter should always use I-voting over casting a paper ballot, if that is a more convenient method (i.e. has a lower cost), thus I-voting should quickly be adopted by some. Voting is a low gain and low cost situation, where small changes can sway the decision (Aldrich, 1993), a small reduction in the costs of voting from the use of a less costly method, might be enough to make someone vote instead of abstaining. The potential gain from I-voting might be neutralized if the technology used is a hurdle and thus an extra cost.

Technological limits were grounded in Rogers (1995) theory of diffusion of innovation, where different users will adopt a new technology at a different rate. This was coupled with Van Dijks (2005) conception, where among other factors skill and usage of previous or required technology increases the speed at which a new innovation is adopted. Two patterns of adoption were discussed: first normalization, where the different levels of technology users adopt I-voting at different times and the general predictive power of technological factors decreases over time; the second was stratification, where adoption is wider among different levels of users and the predictive power of technological factors remains intact.

Three hypothesis were chosen for the thesis: 1) as the cost of conventional voting increases, the probability of I-voting increases; 2) the increase of the probability of I-voting as a function of the

increasing cost of conventional voting is conditional on the level of technological skills; 3) the predictive power of the technological factors decreases over time.

For empirical analysis data from the Estonian I-voters survey was used. For all elections from 2007-2011 random stratified sampled data was available, with an equal share of I-voters, regular voters and abstainers. Logged distance to the polling station was used as a measure of the cost of regular voting. Two different technological factors were considered: skill (using a self-reported measure of computer skills) and usage (using an index variable of internet use).

Larger costs of conventional voting increase the probability to I-vote. This effect is largely independent of technological factors, all levels of computer or internet users are more likely to vote online when they live far away.

Both computer skills and use of internet are reliable predictors of I-voting. People scoring higher on the index were also more likely to vote online. Similarly people with better computer skills were more likely to vote online. Although all categories of computer users did not always reliably differ from each other, in general terms computer skills was always a useful predictor of I-voting. Both technological factors had no interaction with distance, leading to the conclusion that the increase in the chances to I-vote (as a function of distance) is not dependent on technological aptitude. Put simply, the technology used for I-voting is not an insurmountable hurdle and will not prevent people from using it when the cost of conventional voting is large enough.

The predictive power of technological factors did not decrease over time, which is a surprising result, as the actual number of I-voters has increased five times, in 2011 the sample of I-voters was obtained from a quarter of all voters, while in 2007 it was from only a few percent of voters. This led to the conclusion that I-voting became more popular among all groups of computer users, contrary to the assumed model where technologically adept people will adopt it first and others follow later. This was however accordant with van Dijk's (2005) stratification model, where technology based differences remain despite wider adoption.

From the aspect of rational choice the results fit with a situation where people choose the less costly mode to cast a vote, where the initial cost of online voting depends on the previous

experience with computers and the internet and where the cost of voting online decreases over time.

I-voting can slightly improve turnout by reducing the cost to vote. Previous familiarity with computers or the internet makes I-voting a more preferable option, but with high enough costs of regular voting, even the least technology savvy people might vote online. The number of I-voters in Estonia has greatly increased, however technological differences remained intact, indicating that the diffusion of I-voting is taking place among all strata of technology users.

Kokkuvõte

Selle töö eesmärgiks oli hinnata, kas tehnoloogilised piirangud takistavad interneti vahendusel hääletamise (e-valimise) positiivset efekti valimisaktiivsusele. Lisaks muudele positiivsetele omadustele loodeti, et e-valimised pakuvad mugavama alternatiivi hääle andmiseks, mis võib valimisaktiivsust tõsta. Alles hiljuti on Eesti valimissüsteem teinud võimalikuks jälgida e-valimiste mõju üle pikema aja.

Interneti kaudu hääletamine on Eestis olnud võimalik alates 2005. aastast, kasutajaid oli algselt vähe, alla 2% kõigist häältest 2005. aastal, aga osalus kasvas jõudsalt ja 2015. aastal anti peaaegu kolmandik häältest interneti vahendusel. Koguosalus oli nendel valimistel natuke suurem kui varasematel sama taseme valimistel, aga e-valimiste efekti ei ole võimalik eristada tavapärasest valimisaktiivsuse kõikumisest (Vassil, 2013).

Teoreetilise raamistikuna kasutati ratsionaalse valiku teooriat. Ratsionaalne valija peaks alati eelistama e-valimisi tavalisele valimisedelile, kui see on tema jaoks mugavam meetod (e. meetodi kulu on väiksem), järelikult peaks osa valijaskonnast kohe uue meetodi peale üle minema. Hääletamine on madala kuluga ja madala tuluga situatsioon, kus väikesed muutused võivad otsust muuta (Aldrich, 1993), vähem kuluka meetodi kasutamisest tulenev sääst kogukuludele võib olla piisav, et panna kedagi hääletama. Potentsiaalne eelis, mida e-valimised annaksid, võib olla tühine, kui selleks kasutatav tehnoloogia on ise ligipääsu piirajaks ja seega lisakuluks.

Tehnoloogiliste piirangute käsitlemisel kasutati Rogersi (1995) tehnoloogilise innovatsiooni teooriat, mille kohaselt erinevad kasutajad võtavad uue tehnoloogia üle erineva kiirusega. Seda teooriat kombineeriti Van Dijki (2005) konseptsiooniga digitaalsest lõhest, kus muuhulgas oskused ja eelneva tehnoloogia kasutamisharjumused määravad kui kiiresti inimesed innovatsioonilise tehnoloogia omaks võtavad. Toodi välja kaks erinevat omandamismustrit: normaliseerumine, kus erineval tasemel tehnoloogiakasutajad võtavad omaks e-valimise erineva kiirusega ning lõpuks küllastudes kasutamissagedus ühtlustub, misjuhul tehnoloogiliste näitajate ennustusvõime ajas kahaneb; teine oli kihistumine, kus omandamine on laiem erinevate tasemetega kasutajate vahel, misjuhul tehnoloogiliste faktorite ennustusvõime ajas säilib.

Töö jaoks sai valitud kolm hüpoteesi: 1) kui regulaarse hääletamise kulud suurenevad, siis suureneb e-valimistel hääle andmise tõenäosus; 2) e-valimistel osalemise tõenäosuse kasv tavalisel moel osalemiskulude kasvu funktsioonina on sõltuv tehnoloogia kasutamise tasemest; 3) tehnoloogiliste muutujate ennustusvõime on ajas kahanev.

Empiirilise analüüsi tarbeks kasutati Eesti e-valijate uuringu andmeid. 2007-2011. aastal toimunud valimiste kohta olid olemas kihtvalimiga andmed, kus oli võrdne kogus e-valijaid, tavalisi valijaid ning hääletusest loobunud. Tavalise valimiskuluna kasutati logaritmitud vahemaad lähima valimisjaoskonnani. Arvestati kahe erineva tehnoloogilise muutujaga: oskused

(kasutades omahinnangulist arvutioskuste taset) ja kasutamisharjumus (kasutades spetsiaalselt selleks loodud interneti kasutamise indeksit).

Suuremad tavalise valimise kulud suurendavad tõenäosust e-valimistel osaleda. See efekt on suuresti tehnoloogilistest faktoritest sõltumatu, igal tasemel arvuti-ja internetikasutajad hääletavad suurema tõenäosusega interneti vahendusel, kui nad valimisjaoskonnast kaugel elavad.

Nii arvutikasutamise oskused kui ka interneti kasutamise indeks olid head e-valimistel osaluse ennustajad. Inimesed, kes said kõrgema interneti kasutamise indeksi, olid ka sagedamini e-valijad. Sarnaselt olid ka paremate arvutioskustega inimesed tõenäolisemad e-valijad. Kuigi kõikide arvutikasutaja oskustasemete vahel ei olnud alati selget vahet, oli siiski arvutikasutamise oskus üsna heaks ennustajaks e-valimistel osalusele. Kummagi tehnoloogilise muutuja mõju ei sõltunud valimisjaoskonna kaugusest, mis viis teisest hüpoteesist loobumiseni. E-valimistel kasutatud tehnoloogia ei ole piiriks, takistus ületatakse, kui tavalise hääletamise kulu on piisavalt suur.

Tehnoloogiliste muutujate ennustusvõime ei muutunud vaadeldud aastate jooksul oluliselt, mis on üllatav tulemus, sest e-valijate arv suurenes selle aja jooksul viiekordselt. Sellest järeldus, et e-valijate hulk suurenes kõikide arvutikasutajate tasemete seas, vastupidi eeldatud normaliseerumise mudelile, mille järgi e-valijate hulk oleks pidanud suurenema esmalt varasema tehnoloogia tundjate seas ja seejärel laiema kasutajaskonna seas. See tulemus sobis kokku Van Dijki (2005) kihistumismudeliga, kus tehnoloogiapõhised erinevused säilivad ka innovatsiooni laialdase kasutuselevõtu järgselt.

Ratsionaalse valiku seisukohalt sobivad tulemused kokku olukorraga, kus inimesed valivad vähem kuluka meetodi hääle andmiseks, kus interneti vahendusel hääletamise kulu sõltub varasemast kokkupuutest arvutite ja internetiga ja kus e-valimiste kulu väheneb ajas.

E-valimised võivad valimistel osalemise kulu vähendades natuke tõsta valimisaktiivsust. Varasem tutvus arvutite ja internetiga teevad e-valimistel osalemise tõenäolisemaks, kuid piisava vajaduse korral hääletavad interneti vahendusel ka kõige tehnoloogiavõõramad inimesed. E-valijate hulk Eestis on kõvasti kasvanud, kuid erinevused tehnoloogia osas on jäänud muutumatuks, mis annab märku, et e-valimiste levik leiab aset erinevate tehnoloogiakasutajate tasemete seas.

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