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BACKGROUND PAPER

Digital Dividends

Estonian e-Government Ecosystem: Foundation, Applications, Outcomes

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Estonian e-Government Ecosystem

Foundation, applications, outcomes

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1. Introduction

Estonia's use of modern information and communication technologies in public sector and governance has placed the country at the forefront of states that are aiming to modernize their public sector and provide transparent governance. Numerous online public services are available to Estonian citizens and residence including digital identification, digital signatures, electronic tax filing, online medical prescriptions and, ultimately, internet voting. Driven by convenience, most of the services offer efficiency in terms of money and time saved by the users as well as public officials. For example, selling a car in Estonia can be done remotely with less than 15 minutes, filing an online tax declaration takes an average person no more than five minutes, and participating in elections by Internet voting takes 90 seconds on average.

In addition to the number of online public services that governmental offices offer to their 'customers', they are indeed widely used and accepted by citizens. Digital identification, the foundational building block of modern digital democracy, is compulsory for all citizens and in 2014 it was used more than 80 million times for authentication and 35 million times for digital transactions. Ninety five percent of all income tax declarations are filed online, and every third citizen voted online in the last two elections.

Regarding user level attitudes and behavior, survey evidence suggests that governmental online services are regarded as trustworthy and reliable. Citizens expect their provision, and governmental offices see their online presence not as a choice but as a strategic and inevitable part of their day-to-day operations.

Yet, surprisingly little is known what exactly has fuelled Estonia's rapid development and subsequent supremacy in the field of e-government. What is the foundation that has facilitated the growth of e-services and what is the impact on e-government on individual as well as the institutional level. Does it impact upon economic outcomes and bring about fiscal savings?

The purpose of this report is to analyze how and which policies, institutions, technologies and other factors have contributed to the development of a vibrant e-government ecosystem in Estonia; Understand which e-services have attracted the widest usage and render highest fiscal returns as well as efficiency to the government; Investigate the impact of top e-services on the digital development of the country, as well as individual level behavior.

Basic facts about Estonia

After regaining independence in 1991, Estonia has become a full member of the European Union and NATO (joined in 2004), OECD (since 2010), and the Eurozone (since 2011). Estonia is a parliamentary representative democratic republic, where the Prime Minister is the head of the government.

According to 2011 census 1.29 million people live in Estonia, which is 5.5% less than in 2000. About 54% are female, 68.7% define themselves as ethnic Estonians, 24.8% as ethnic Russians and 4.9% as of other ethnicities (refer to Box 1).

Box 1: Basic facts on Estonia (to be inserted where relevant)

Population:	1 294 236
Area:	45 227 km^2
Currency:	Euro (since 2011)
Capital:	Tallinn
Administrative divisions:	15 counties, 213 municipal districts including 30 towns and 183 parishes

Estonian economic growth was about 7% per year between 2000 and 2008, which placed it amongst the top three fastest growing economies in EU (increasing GDP per capita from 45% of the EU27 average in 2000 to 67% in 2008).[1] Economic crisis of 2008 did impact Estonia's economy by decreasing the GDP growth to 14.7% in 2009. Since 2010 economic growth has turned positive again – in 2014 Estonian economy grew 2.1% compared to 2014 and the economic growth in 2016-2017 is expected to hover around 3%.[2] In 2014 Estonian GDP was 14 853 euros per capita which is about 73% of EU28 average.

2. Foundations of Estonian e-government ecosystem: digital identification

Estonia's success in converting their public services online is first and foremost based on the widespread use of electronic identification cards. Since 2002 about 1.2 million of these credit-card size personal identification documents have been issued allowing citizens to digitally identify themselves and sign documents or actions.

ID-cards are compulsory for all citizens and they are equally valid for digital and physical identification. Due to their convenient size (they fit better into a regular wallet than a passport) they are often used as the only identification document that people carry around. Physically, they are valid for identification in Estonia, but more importantly, they are also valid for travel in most European countries. Thus, in addition to their primary functionality – digital identification – ID-cards are effectively used as replacements for traditional identification documents (see Figure 1).

[1] http://estonia.eu/about-estonia/economy-a-it/a-dynamic-economy.html
[2] https://www.eestipank.ee/en/press/eesti-pank-raised-its-forecast-economic-growth-year-and-lowered-its-forecast-next-year-23092014

Figure 1. Estonian electronic ID-card

The digital functionality of an ID-card is based on an electronic chip and the two pin codes supplied with the card. By using a smart card reader and a computer connected to the internet, citizens can use two core functionalities provided by the ID-card, both of which are essential to the development of e-government – personal authentication (related to the PIN1) and digital signature (related to PIN2).

The first pin-code allows citizens to authenticate their identity so that the corresponding e-service knows the identity of the user. This is a first step that provides basic enabling infrastructure to provide personalized services and information via online means. Many services run entirely on authentication only basis, i.e., reviewing individual health records, checking the validity of car insurance or reviewing the list of political candidates in voter's district. The second pin-code is used to sign documents or approve transactions online. For example, acquiring the insurance policy, confirming the submission of the tax declaration, or casting a vote in elections.

Functionally it is important to distinguish between authentication and signing as they enable different kind of services. Internet voting is perhaps the best example to illustrate the difference. When voting online, citizens download a voting application to their computer and upon the request from the system have to first identify themselves using the ID-card and the first pin-code so that the voting system knows who is behind the computer. Next, the system checks whether the voter is eligible to vote in these elections and if affirmative, displays a list of candidates in her district (Figure 2: A). This is the part of the service that uses the authentication functionality of the digital ID-card and allows eligible voters to browse between political candidates. No digital signature is required thus far. However, in order to cast an e-vote, the second pin-code – the signing function - will be used to confirm voter's choice. The latter is a transactional part of the citizen-state communication. When inserted correctly, the electronic vote is sent to the server and will be counted at an appropriate time as prescribed by the procedures of online voting (Figure 2: B).

A. B.

Figure 2. Screenshots of Estonian internet voting system. Side A: the list of candidates displayed to the user after checking the eligibility using the authentication part of the digital ID (pin 1). Side B: confirming the vote choice by using the transactional part of the digital ID (pin 2).

The difference between authentication and transaction is pivotal as in virtually all aspects of public e-services, depending on the nature of services, users are required to use the digital ID either for authentication, digital signatures or both. A very similar example is applicable to online banking, where customers first use their first pin code to enter their account, check the balance, browser their assets and so on. However, should they intend to make an actual money transfer (a transactional part of the service), the second pin code is used.

The major institutional precondition for digital identification is the national identification system, which helps to uniquely identify Estonian residents; and the Population Register that is the largest central data repository for personal data and family events.

Legal framework and safeguards for data protection, privacy and security

In addition to technology and architecture, Estonian e-government ecosystem is strongly regulated by legal instruments that provide framework for security and protection of the personal data stored within Population Register and other relevant government data repositories. Jointly these norms regulate the process by which institutions, individuals and companies can request and receive access to information stored in government databases and thereby build new public e-services by using the information already stored in state's databases.

The legal framework is designed to work seamlessly with the technological solutions of e-government. For example, when a new public e-services are developed it is legally not permitted to design systems that store the same data in different repositories. In practical terms it means that, if citizen's age is stored in Population Register, it will be retrieved automatically for checking her eligibility for voting, driving, etc., not collected additionally by the system of internet voting. Simplified example though it may be, it shows how information stored in one repository can be reused by another. Moreover, Estonia's Public Information Act[3] prohibits to establish separate databases for the collection of the same data. In practice it means that state institutions cannot repetitively ask for the same personal information if it is already stored in any of the data repositories connected to the X-Road – a data exchange platform that connects all e-governance applications. This is an example of interconnectedness between enabling technologies and regulatory acts designed to work for a common goal – better citizen-sate interaction.

The following norms are most relevant in regard to Estonian e-governance and jointly provide the foundation for the entire range of application development, data protection and security issues in the realm of e-governance.

Table 1. Legal norms providing the institutional background for Estonian e-governance

Act or Decree	Brief summary
Personal Data Protection Act (1996)	The aim of this Act is to protect the fundamental rights and freedoms of natural persons upon processing of personal data, above all the right to inviolability of private life. This Act provides for: 1) the conditions and procedure for processing of personal data; 2) the procedure for the exercise of state supervision upon processing of personal data; 3) liability for the violation of the requirements for processing of personal data.[4]
Public Information Act (2000)	The purpose of this Act is to ensure that the public and every person has the opportunity to access information intended for public use, based on the principles of a democratic and social rule of law and an open society, and to create opportunities for the public to monitor the performance of public duties.[5]
Population Register Act (2000)	This Act provides for the composition of data in the population register and the procedure for the introduction and maintenance of the population register, processing of data and access to data in the population register, entry of data on residence in the population register and exercise of supervision over the maintenance of the population register.[6]
Digital Signatures Act (2000)	This Act provides the conditions necessary for using digital signatures and digital seals, and the procedure for exercising

[3] https://www.riigiteataja.ee/en/eli/522122014002/consolide
[4] https://www.riigiteataja.ee/en/eli/512112013011/consolide
[5] https://www.riigiteataja.ee/en/eli/514112013001/consolide
[6] https://www.riigiteataja.ee/en/eli/516012014003/consolide

	supervision over the provision of certification services and time-stamping services.[7]
Electronic Communications Act (2004)	The purpose of this Act is to create the necessary conditions for the development of electronic communications to promote the development of electronic communications networks and electronic communications services without giving preference to specific technologies and to ensure the protection of the interests of users of electronic communications services by promoting free competition and the purposeful and just planning, allocation and use of radio frequencies and numbering.[8]

Usage of digital ID

Given the fact of how fundamentally digital ID is linked to the public online services, our next question is to investigate how frequently it has been used and what is its pattern of diffusion in the society? In order answer this question we acquired aggregate log-file data on the usage of digital ID over time.[9]

The digital ID project started already as early as in 1998 when Estonia had sought solutions on how to digitally identify their citizens. By 1999 a viable project in the form of current ID-card was proposed and the legal framework to enable digital identification was set up in the following years. In 2000 the Identity Documents Act and the Digital Signatures Act, the two most important bills regulating the use of digital ID's, were passed in the parliament. The first states the conditions to which an ID-card must adhere to, but most importantly states that the ID-card is compulsory for all Estonian citizens. The latter, states the conditions for a state-governed certification registry, which is fundamentally linked to the functioning of the digital ID-card.

Following these events, the first ID-cards where issued in January 2002. Since then about 1.24 million of digital ID-cards have been issued. By the end of 2014 digital ID-card has been used about 315 million times for personal identification and 157 million times for digital signatures. An average annual growth rate over 12 years (from 2003 to 2014) amounts to about 7.4 million authentications, and about 3.5 million signatures per year. In other words, the growth rate for digital identification is about two times more rapid than for signatures. But the growth in ID-card users has been all but swift and instantaneous (see Figure 3).

[7] https://www.riigiteataja.ee/en/eli/530102013080/consolide
[8] https://www.riigiteataja.ee/en/eli/ee/Riigikogu/act/501042015003/consolide
[9] We thank Liisa Lukin and Tanel Kuusk of Certification Center for their assistance and help in acquiring the usage on data on digital ID.

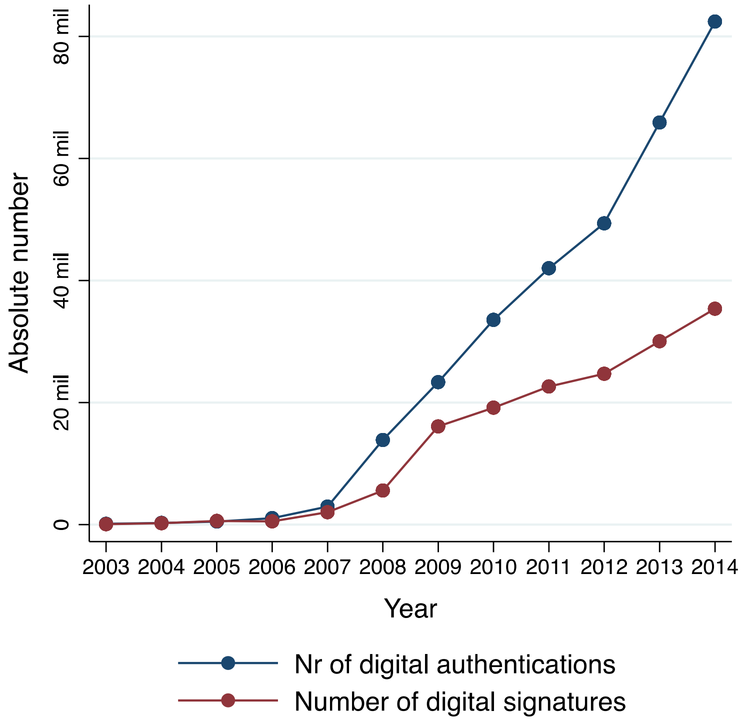

Figure 3. Growth of digital authentications and signatures over time (from August 2003 until March 2014)

When the project started in 2002 the electronic use of digital ID's remained low for almost 5 consecutive years. As seen from the graph, the situation changed in late 2007 after which the usage of ID-cards started to grow rapidly reaching an all time high in 2015. Why did it take so long and what triggered the sudden growth in 2005?

In order to respond to this question, we need to understand the context in which Estonia was in early 2000s. In the beginning of the new millennium less than one third of Estonians had used the Internet. A study about digital divide, carried out in 2002, characterized Estonia as a country with relatively few internet users, limited access to the computers and a growing, but still not sufficient number of public internet access points (Kalvet, 2002). People still could not afford computers or internet connections in their homes. However, the major obstacle to make use of new technologies, as noted by the study, was not the lack of infrastructure *per se*, but the lack of skills and motivation (ibid). As noted by the authors of the study:

> "The main barrier in Estonian society is the fact that the possibilities offered by the Internet are not associated with personal needs. It is believed that "computers are not for me"" (Kalkul & Kalvet, 2002: 9).

Indeed, the beginning of 2000s characterize Estonia as a society with gaping digital divide and it was, effectively, a disconnected society. The low usage of ID-cards throughout 2000 reflects this situation appropriately.

Solution

Although the problem of a digital divide is primarily a societal one, the solution was provided from a rather unexpected source: the private sector. Namely, the low number of internet users and paper-based means of identification of the people turned out to be an even larger concern for the banking and the telecom industry. Indeed, it was the banking sector that wanted to replace the physical pin-code cards with a more reliable and secure way of identifying their customers; and it was also their interest to move the bulk of financial transactions out of their physical offices onto digital realm. Because the banking, as well as the telecom sector had prospered when compared to other industries at the time, they also had financial means to support the larger vision on how to help the society in raising awareness in modern information and communication technologies.

Several coinciding events comprising of state's involvement in the development of ID-card, telecom and banking industry's concern to reach out to the society and previous attempts to digitize country's educational infrastructure (the Tiger Leap project[10]) provided fertile ground to one of the largest public-private partnership projects in Estonia to this day – the Look@World project.

The goal of this project was ambitious, yet simple: to promote the spread of the Internet among the population of Estonia. With four founders from the private sector (two largest banks and two telecom companies) the consortium initiated a 40 million kroon project over the course of two years (2001-2002). As an outcome of this massive partnership more than 100 000 individuals, i.e., about 10% of Estonian adult population, was taught to use and understand ICTs. The project raised the number of public internet access points from 200 in 2001 to about 700 in 2004. Through the years, the consortium worked hand-in-hand with the public sector and in 2001 the Look@World consortium members agreed to facilitate the widespread use of ID-cards and later, in 2002, the private banks were given the right to deliver digital ID-cards in their offices.

The involvement of private banks was pivotal with regard to the success of the ID-card – both regarding societal awareness as well as the actual distribution of cards. First and foremost, their relevance lies in the unconditional support of the ID-card infrastructure as a primary mechanism to identify its customers. If the banks would not have made a strong case toward the support of the ID-card and continued to advertise both the new, as well as the old paper based pin-code system, the transition would have take considerably more time. More importantly, it shows that the spread of a new identification mechanism is strongly related to the number of services that it supports and makes available to people.

In particular, when people realized that their banks preferred digital ID's for personal identification, that it was more secure and convenient, they had an actual motive to replace old identification methods with the digital-ID. When income tax declaration was moved online Estonian Tax and Customs Board promised a swift review of declarations and (if applicable) a quick tax return. In fact the tax returns for those using

[10] Box: *Tiger's Leap* was a governmental project that started in 1997 with the goal to substantially increase the investments into the development and expansion of personal computers and network infrastructure in Estonia, with a particular emphasis on education. The primary outcome of the project was the provision of Internet access and computer labs to all Estonian schools.

e-declarations was less than a month as compared to a typical 3-6 month period for those who submitted their tax declarations offline. Such incentives alongside with the growing number of new e-services provided a sustainable environment for the increasing use of digital identification.

In other words, by using new digitized public services people gradually learned that using their digital identity cards provides them with a quicker and more efficient channel to interact with private and governmental services. Growth in digital ID usage does not operate therefore in isolation, but is clearly dependent on the amount of services rendered to the public for which digital ID is used. Consequently, this explains the low takeoff pace in the early years of ID-card (see Figure 3).

In order to demonstrate that the usage of ID-cards is indeed closely related to the number of services provided, we also acquired data from the Estonian Information Authority on a number of data repositories used to render public e-services. Figure 4 shows a strong positive association between the number of services (as measured by the number of data repositories) and the number of personal digital authentication. The time span covered in the data covers the period between 2003 and 2014

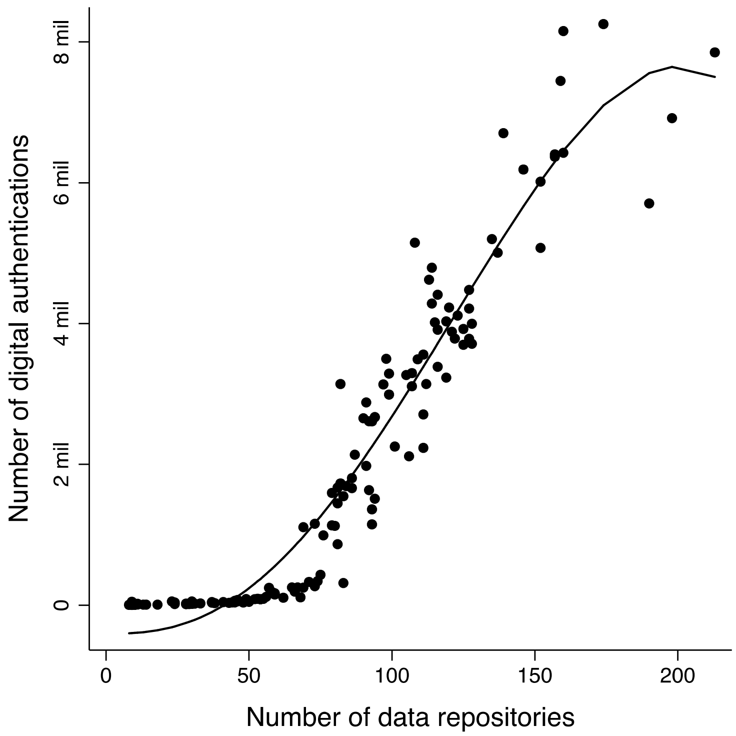

Figure 4. Relationship between the number of data repositories and digital authentication

As one can see until the 75th data repository the growth of digital authentications is very slow and almost linear. Further data examination showed that the 75th data repository was added to the Estonian e-governance ecosystem approximately in the late 2007, which is incidentally also the start of increasing number of digital authentications in Figure 3. From Figure 4, we can additionally infer that it takes considerably more than just one, two or even dozen data repositories to be connected to the ecosystem of e-government before the spread of digital identification starts to surface.

We believe that the lagged effect of ID-card usage is applicable to many other domains in e-governance and, thus constitutes a more universal law on the diffusion of technology in the public sector. Technological innovations do not jump from no-usage to full-usage overnight. Instead, their spread is slow in the beginning, but when managed appropriately, after certain period, their usage takes off and turns into rapid, often into exponential, growth.

However, digital identification is only *one* necessary precondition for a functioning e-government. The second, as relevant as digital ID, is related to enabling technological design, i.e., how to provide a secure and reliable technological environment where different state institutions are incentivized to work together, share their data and develop online services. Estonia's solution to this fundamental question was to develop an X-Road, a data exchange layer that makes it easy for any institution – public or private - to push their services online. In the next section, we look at the functional part of X-Road and using the data collected by it, estimate its fiscal impact.

3. Foundations of Estonian e-government ecosystem: the X-Road

As technology is the primary enabler of e-governance, the critical question is how to ensure secure communication between scattered government databases and institutions that use different procedures and technologies to deliver their services. Estonia's solution to this problem was to develop the X-Road, a secure internet-based data exchange layer that enables state's different information systems to communicate and exchange data with each other.

X-Road serves as platform for application development by which any state institution can relatively easily extend their physical services into an electronic environment. For example, if an institution, or a private company for that matter, wishes to develop an online application it can apply for joining the X-Road and thereby automatically get an access to any of the following services: client authentication (either by ID-card, mobile-ID or the internet banks authentication systems); authorization, registry services, query design services to various state managed data depositories and registries, data entry, secure data exchange, logging, query tracking, visualization environment, central and local monitoring, etc. These services are automatically provided to those who join the X-Road and they provide vital components for the subsequent application design. Therefore, X-Road offers a seamless point of interaction between those extending their services online and different state-managed datasets and services. The conceptual logic of the X-Road is depicted in Figure 5.

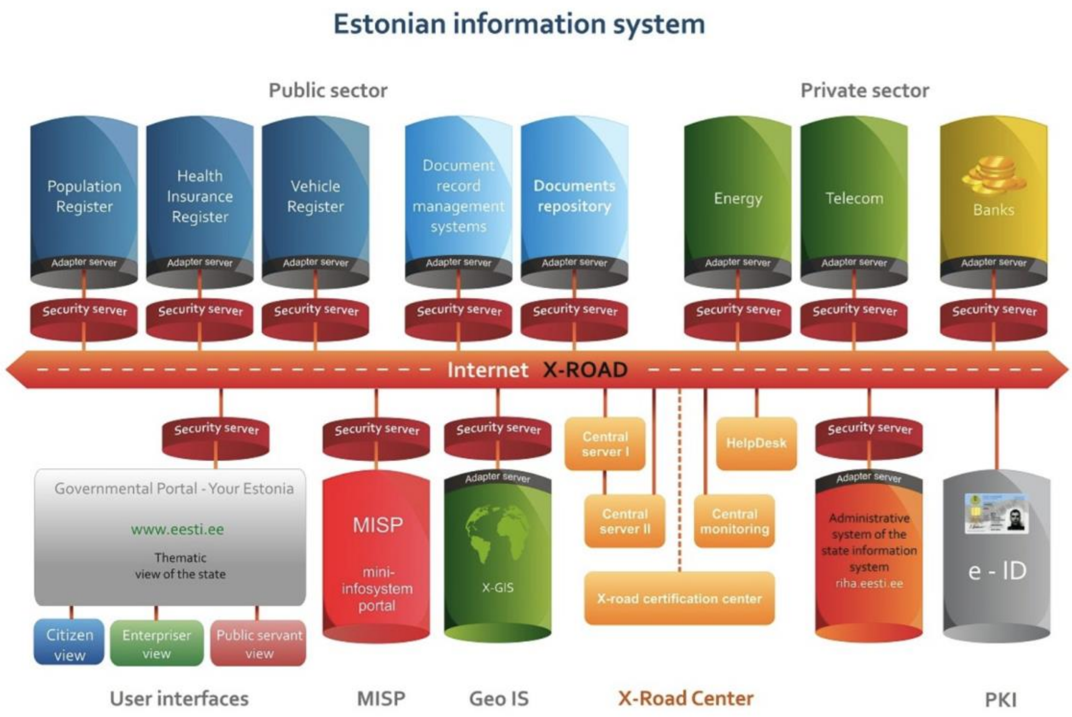

Figure 5. Schematic structure of X-Road as a data exchange layer between governmental and private services

Another important feature of X-Road is its decentralized nature. X-Road is a platform, an environment, for efficient data exchange, but at the same time it has no monopoly over individual data repositories that belong to those institutions that join the X-Road. Moreover, by its very design X-Road requires every joining institution to share their data with others if required and necessary. As such, every joining institution, every developed application can use the data stored in other repositories and is even legally encourage to do so in order to avoid repetitive data collection from the client side. Because the data sharing enables development of more convenient services than those institutions would be able to pull of single handedly, this system implicitly incentivizes the reuse of the data. The incentive works because such a collective process allows for a seamless and more efficient user experience and thus increases the interest, both form state institutions to develop digital services as well as individuals to reach out to the state.

In addition to citizen-state interaction X-Road is particularly suitable for queries involving multiple agencies and information sources. For example, checking the vehicles registration data requires data retrieval from the population registry and vehicle registry – the two unconnected data repositories. According to the State Information Authority, the conventional offline approach would require 3 police officers working on the request for about 20 minutes. With the X-road, the entire information retrieval is conducted by one police officer within seconds. At the same time, citizens are not even required to carry their driving license or car's registry documents around, as the information system that the police uses, displays the status of these documents in real time.

Similarly, but in more complex terms, Figure 6 shows how many interfaces and datasets are jointly working to provide parents with an option to apply for a parental benefit.[11] As one can see, the citizen interacts with the government through the Citizens' portal (which is the access point to most of the governmental e-services); the civil servant (if at all) works through the mini information system portal (MISP) and the X-Road provides the access to all relevant data repositories that are needed to for one goal – process the parental benefit application.

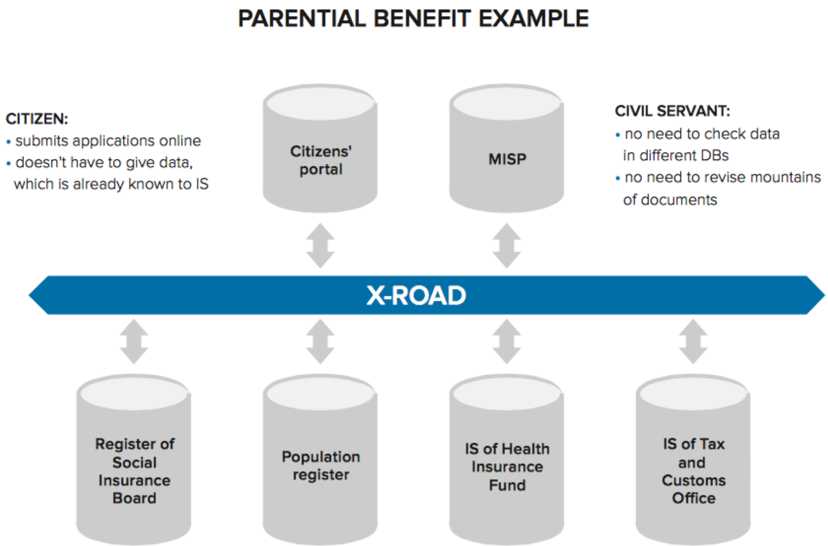

Figure 6. Parental benefit application system

Naturally, this open design is accompanied by rigid security measures – authentication, multilevel authorization, high-level log processing and monitoring, encrypted and time stamped data traffic – the basic functionalities that are covered within the very structure of X-Road.

As a result, Estonian state institutions are structurally incentivized to join the X-Road, simply because they can design services that would not be as efficient and convenient to develop and maintain individually.

The impact of X-Road

Our next task is to understand the fiscal impact of X-Road. In other words, we seek to understand how many institutions have actually joined the X-Road to render their services online, and more importantly, how many actual services are provided through X-Road to how many end-users?

[11] Retrieved from: https://www.ria.ee/public/x_tee/Xroad-technical-factsheet-2014.pdf

In order to respond to these questions, we acquired relevant time-variant data on X-Road usage numbers from Estonian Information System Authority. [12] We begin by the question on how many services are offered in X-Road by how many institutions. Figure 7 displays relevant growth rates for services and institutions that have joined X-Road since 2003 (the data are aggregated on a monthly basis). As a reference, we also plot the number of data repositories upon which those services run, but we return to this feature later in the report.

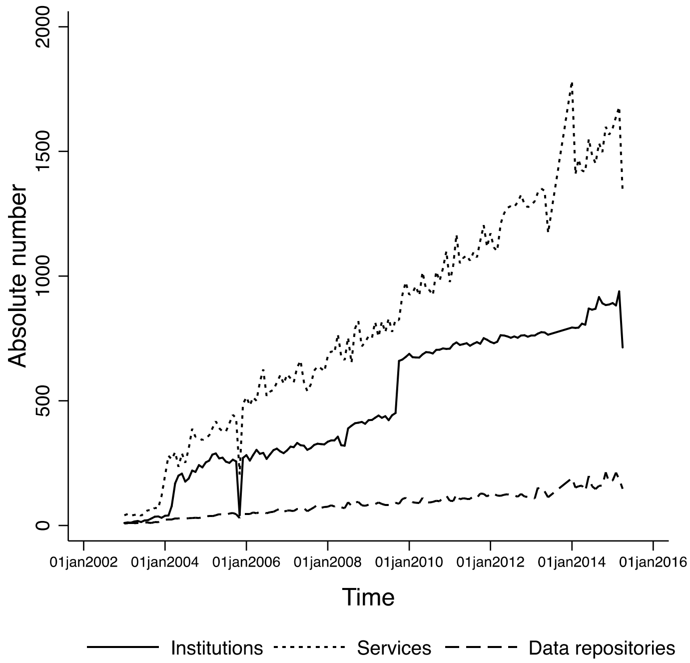

Figure 7. Number of institutions services and data repositories connected to X-Road (monthly data)

Let us being by considering the curve showing the growth of services over time. Services include both, the actual end-products that citizens can use, but also those services that, for example, public servants use in their day-to-day work. The latter may include a policy officer retrieving information from population registry in checking one's vehicles registration, or a law office clerk checking your property ownership. Thus, the number of services does not reflect the actual number of those services that we think of as part of e-government but all interactions between systems that exchange information in X-Road in order to run certain applications (the end-product).

We would prefer, naturally, reporting the amount of actual applications available for citizens, but those are unfortunately not logged by the system, so we have to rely on a proxy measure – services. According to Figure 7 the total number of services has grown

[12] We thank mr. Hillar Aarelaid for his assitance in extracting the data from the log storage server and making it available for machine processing.

from around 40 in 2003 to more than 1600 in 2015. An average annual growth of services amounts to about 121 services.[13]

The growth of institutions follows a similar trend at the slightly lower level. X-Road had only about 10 institutions offering their services in 2003. However the number grew quickly to almost 900 by 2014. Notice that the number of institutions includes both public institutions at the central and local government level and private companies. The share of public institutions was about 71 per cent in 2014.

Also notice the two periods where the number of joining institutions have grown very quickly (one in 2006 and the other in 2009). Those are the outcomes of two extensive communication campaigns directed to public institutions and citizens to encourage the use of Estonian e-governance system. The annual growth of institutions is about 86, meaning that with every advancing year since 2003, on average, 86 institutions have joined the X-Road to rendering their services online.

Finally, we can also observe the number of data repositories that are connected to the X-Road. This is a very interesting characteristic to look at, because data repositories are the key building blocks for final products (the applications). To be sure, the number of data repositories does not equal the number of services, because one can build several services on one data repository and even more when interacting multiple repositories.

Figure 7 demonstrates that the growth of the number of data repositories is quite modest when compared to those of the growth of institutions and services. Indeed, in 2003 only 18 databases where connected to the X-Road. From there onward the growth has been stable but quite small, only about 15 databases per year. The highest peak was in 2014 when 213 data repositories were connected to X-Road. However, what makes the growth of datasets more interesting than other components of X-Road, is indeed their enabling nature, i.e., in itself the dynamics of data repositories is not particularly interesting, but because they provide the foundation for application development, their association with actual usage of X-Road services is extremely relevant.

The next step in understanding how much time and money X-Road helps to save is to look at the number of actual end-users making use of services provided through X-Road. Figure 8 achieves to illustrate the growth of end-users over time (aggregated to annual basis).

[13] Linear estimation obtained by regressing the time on the number of services.

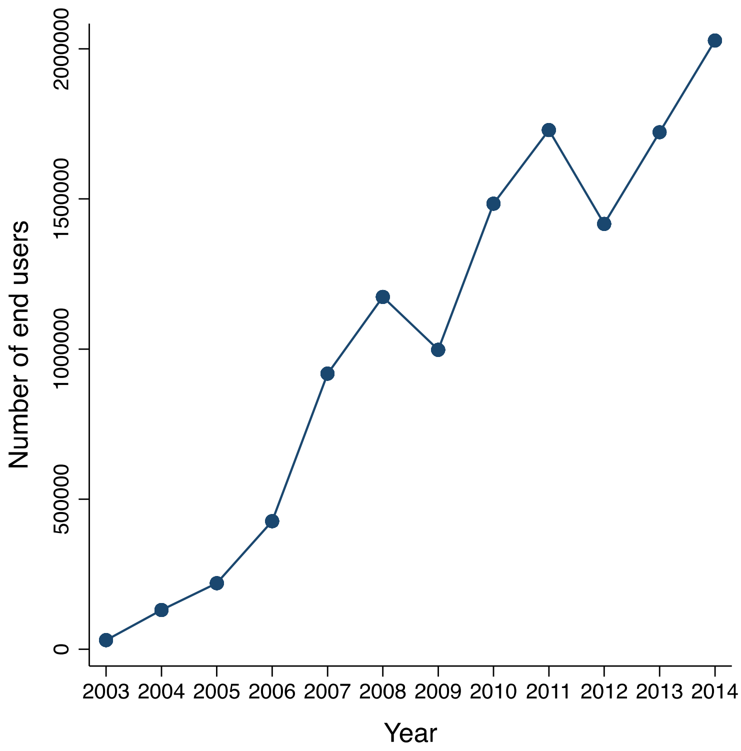

Figure 8. The growth of end-users in X-Road over time
(period covered from January 2003 until December 2014)

We observe the growth of end-users from around 30 000 in 2003 to slightly over 2 million in 2014. An annual estimated growth rate of end-users is about 153 000, which translates into the growth of 41 end-users per month over the course of last twelve years.[14] The fluctuations in user numbers (sharp peaks in absolute numbers and waves in smoothed averages) reflect the impact of public information campaigns that encourage citizens to use specific e-services at specific time periods.

Fiscal impact of X-Road

Our next task is to understand the fiscal impact of X-Road. The best proxy measure to this end is the number of queries that have been made within the X-Road. Queries between different systems demonstrate the actual bloodstream of X-Road because every query is a point of interaction that substitutes conventional services and thus has the potential to save time and money. Figure 9 demonstrates the growth of queries over time.

[14] Linear regression estimation obtained by regressing time on the number of users.

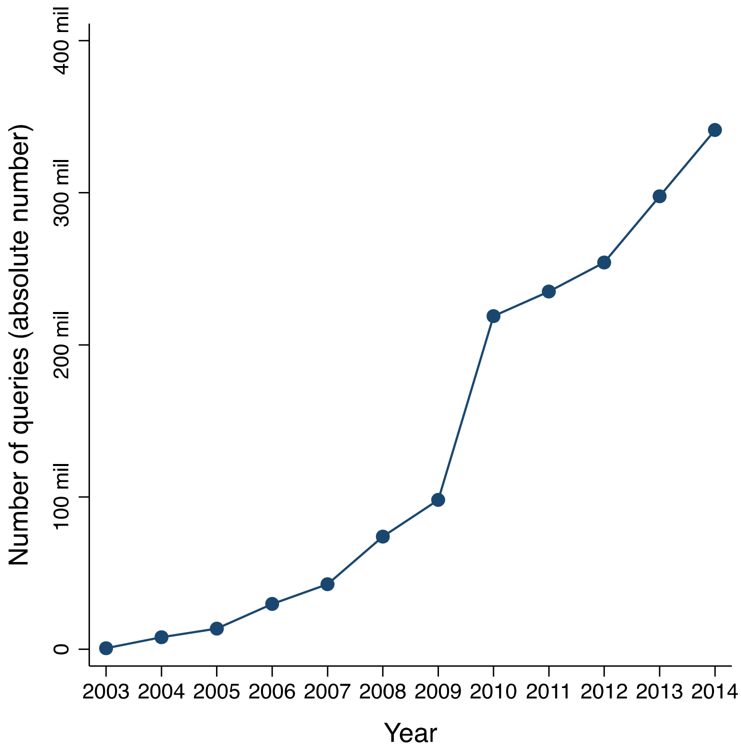

Figure 9. X-Road's bloodstream: the number of queries within X-road (personal and system queries combined).

There are to important inferences that can be made on the basis of Figure 9. First, as shown with the growth of ID-cards in earlier sections of this report, the number of queries does not jump high immediately after the kickoff of X-Road. Quite the contrary, it takes several years before the number of queries start to visibly increase.

However, the growth, albeit its slow start in the beginning, reaches a point in early 2010 when the number of queries rapidly burst to more than double of its previous value. Mathematically, it is often referred to as a form of a non-linear growth rate in a form of an exponential function. It is the more surprising, because any other parameter that we have looked at before (the spread of ID-cards, institutions, data repositories, services) grows almost linearly.

Next, an interesting association appears between the number of queries and the number of databases connected to X-Road. As mentioned earlier, databases are the nuclear entities of an effective e-government and allow building e-services in the first place. The more data repositories connected to X-Road, the more services can be built. The question is how many actual queries one gets per connected database and how are the growth of data repositories related to the growth of queries?

These questions are relevant for any country looking for ways to digitize their public services with the aim to attract the widest possible audience. Figure 10 provides the answer to this question. First, it shows that the number of data repositories is initially only modestly associated with the growth of queries (notice that the data are aggregated to a monthly level). Until the 50th dataset the change in queries remains marginal. However, from the 50th repository onwards the growth turns to exponential.

Effectively, this is the evidence that building an effective e-government does not happen over night. Instead it will take time and above all, hinge on the number of separate databases that can be incorporated to the kind of a system like the X-Road upon which institutions can subsequently start building their end products for users. The discrete threshold for growth appears at 50 data repositories.

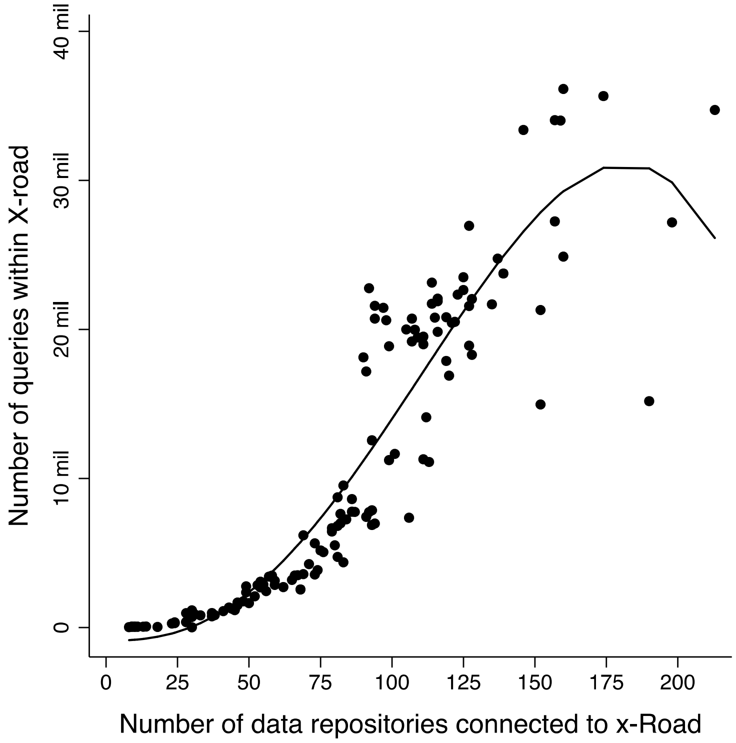

Figure 10. The relationship between the number of queries in X-Road and the number of data repositories connected to it.

Coming back to the nominal growth of queries made within the X-Road we can make inferences about the potential fiscal impact of Estonia's e-government ecosystem. According to Estonian Information Authority system about one third of all queries are those conducted between individuals, i.e., citizens and public officials. We take this approximation as point of departure and argue that every query (i.e., interaction within the Estonia e-government ecosystem) replaces physical citizen-state interaction with the virtual one. We further argue that every interaction replaced saves time, both from the citizen as well as the public official ultimately yielding a time saved. Conversely, that time would not have been saved in the absence of X-Road and e-governance.

In order to calculate the plausible fiscal impact we assume that every query saved 15 minutes of citizen's time. Considering that the time cost involves coming and going to the state institution, locating the relevant public official, booking the time and queuing (if necessary), we are confident that the 15 minute time-saving is a conservative measure. Next, assuming that the time saved was indeed 15 minutes we can further extrapolate the time that was saved based on the number of X-Road queries at any given year. For example, in 2014 the annual of human-to-human queries was approximately 113 million. It means that if every query saved 15 minutes a total of 2.8 million hours, or 3225 years of time was saved. The comprehensive and intuitive interpretation of this number would posit that a time saved by X-Road in 2014 amounts to 3225 people working continuously 24/7 for one year. Figure 11 displays the corresponding values for each year since 2002 and further illustrates the time-saving curves for alternative time saving scenarios, i.e., assuming that instead of 15 minutes X-Road only saves 5 minutes, or as much as 30 or 60 minutes. Because this is the only assumption in computing the potential fiscal impact of X-Road and there is no opportunity for an empirical validation we believe that calculating alternative scenarios best describe the potential of Estonia e-government ecosystem.

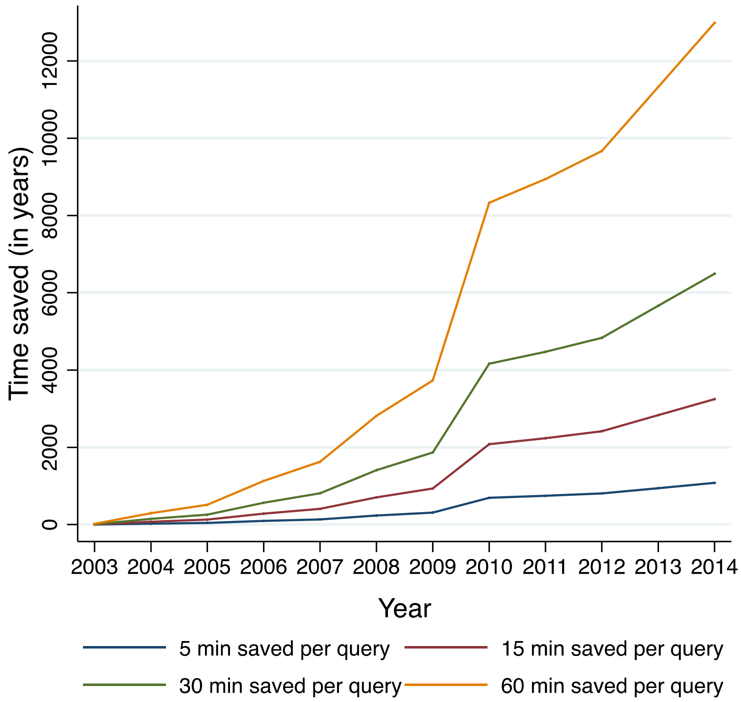

Figure 11. Time saved (in years) per year due to the availability of public e-services. How to read guide: For example the red line assumes that X-Road saves citizens 15 minutes. In year 2010 it is at about 2000 years saved, which means that the time saved is approximately equal to the amount of time when 2000 people would work for one full year 24/7 (or conversely, if one man would work continuously for 2000 years).

Although there is no empirical validation available, we argue that it is reasonable to expect that time saved by X-Road is between 5 and 60 minutes. In such a case the representative mean value is in all likelihood close to 30 minutes and the corresponding fiscal impact can be interpreted accordingly. Notice, that the entire annual budget of 2014 of the State's Information Authority (that administers the X-Road) was about 14.2 million - a fraction of what was actually saved in time for citizens in 2014.

Naturally, one should be cautious of taking this impact estimation at face value. Several factors for which no data are available can influence time savings in both directions. That said, we believe that it is a simple, powerful, yet a fairly conservative assessment of the tangible fiscal impact of e-governance.

In the next section we depart from X-Road as an enabling technical infrastructure for application development and explore one of the most tangible forms of citizen-state interaction in the realm of e-governance – the internet voting.

4. Internet voting

Since the restoration of independence in august 1991, Estonia has held 17 elections at the local, national and European levels. With the population of about 1.3 million (according to the 2011 census) the size of Estonian electorate is below 1 million[15] depending on the type of election (Table 2). The size of Estonian electorate varies due to the fact that non-citizens are eligible to vote in local but not in national elections. Turnout levels are comparable to other European countries, which, together with the institutional development, economic freedom and low levels of corruptions, EU and NATO membership as well as the Eurozone, have made Estonia a consolidated and developed democracy.

The major global innovation in voting technologies is the introduction of remote internet voting. Several countries, including Switzerland and Canada have piloted and effectively used means of internet voting. However, Estonia is the only country in the world thus far to offer its citizens a statewide opportunity to cast legally binding votes over the internet. Since 2005, Estonia has used a total of eight elections at the local, national and European levels where people can cast their votes online (refer to Table 2).

Table 2. Elections in Estonia since 1992

Date	Type of election	Electorate	Turnout	Internet voting
1992 Sept 20	National	689 319	67.8	No
1993 Oct 17	Local	880 296	52.6	No
1995 Mar 5	National	790 392	69.1	No
1996 Oct 20	Local	879 034	52.5	No
1999 Mar 7	National	857 270	57.4	No
1999 Oct 17	Local	1 052 404	49.8	No
2002 Oct 20	Local	1 021 439	52.5	No

[15] Average size of the electorate over all 17 elections is 921594

2003 Mar 2	National	859 714	58.0	No
2004 Jun 13	European	873 809	27.0	No
2005 Oct 16	Local	1 059 292	47.0	Yes
2007 Mar 4	National	897 243	61.9	Yes
2009 June7	European	909 628	43.9	Yes
2009 Oct 18	Local	1 094 317	60.6	Yes
2011 Mar 6	National	913 346	63.5	Yes
2013 Oct 20	Local	1 086 935	58.0	Yes
2014 May 25	European	902 873	36.5	Yes
2015 Mar 1	National	899 793	64.2	Yes

The process of internet voting and basic technical setup

In order to vote online, people are required to use their digital identification card and the computer connected to the internet equipped with the smart card reader. Next, they need to download a voting application which is a standalone program for Estonian e-voting. Using their ID-card and the PIN1 the user has to first identify herself with the system after which the system checks whether the voter is eligible to vote in these elections. If affirmative, e-voting system displays the list of candidates in voter's district (Figure 12: A).

Voters can then browse the list of candidates and decide for whom to vote for. In order to cast an e-vote, the voter will choose a candidate and after providing PIN2 the vote is electronically cast. When inserted correctly, the electronic vote is sent to the server and will be counted at an appropriate time as prescribed by the procedures of online voting (Figure 12: B).[16]

[16] Refer to http://vvk.ee/public/dok/E-voting_concept_security_analysis_and_measures_2010.pdf

A. B.

Figure 12. Screenshots of Estonian internet voting system. Side A: the list of candidates displayed to the user after checking the eligibility using the authentication part of the digital ID (pin 1). Side B: confirming the vote choice by using the transactional part of the digital ID (pin 2).

The technical setup of the system of internet voting is derived from the traditional ways to vote outside the polling district of the voter's residence – the postal voting. In postal voting, a two-envelope system is used to cast a vote. The inner envelope contains a ballot with voter's vote choice, but has no identification markings. The outer envelope contains voter's identification information. When sent to the ballot station, the information on the outer envelope is used to verify voter's eligibility to vote and if confirmed, the inner envelope will be separated from the outer envelope and put into the ballot box for counting.

The system of internet voting in Estonia works in a similar fashion. The downloaded e-voting application encrypts the vote (PIN1). The encrypted vote can be regarded as the vote contained in the inner, anonymous envelope. After that the voter gives a digital signature to confirm his or her choice (PIN2). By digital signing, the voter's personal data or outer envelope is added to the encrypted vote. Before the ascertaining of voting results in the evening of the Election Day, the encrypted votes and the digital signatures (i.e. the data identifying the voter) are separated. Then anonymous I-votes are opened and counted. The system opens the votes only if they are not connected to personal data.[17] Figure 13 displays the conceptual two-envelope system of internet voting graphically.

[17] Source and more information available at: http://vvk.ee/voting-methods-in-estonia/

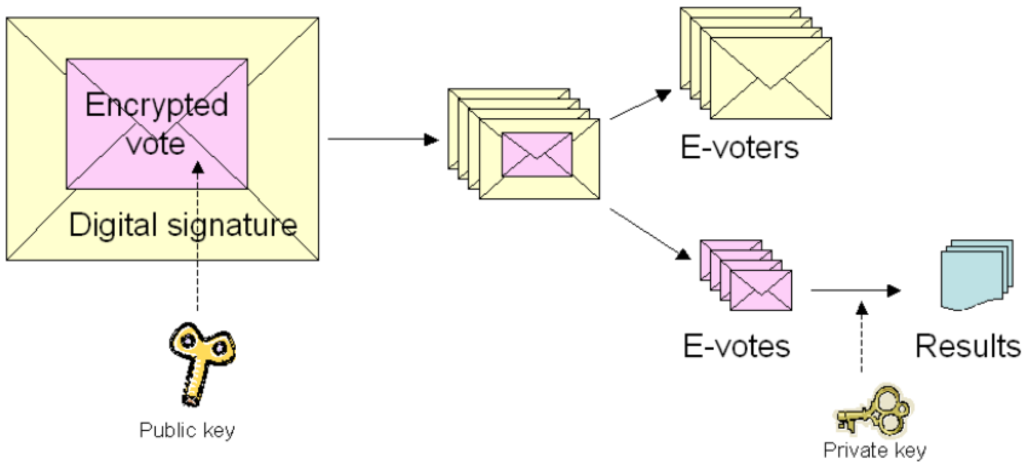

Figure 13. The two-envelope concept behind Estonian internet voting system[18]

Secrecy of the vote and vote verification

An often-debated issue in terms of internet voting is the question on how to ensure vote secrecy in an unsupervised environments. Because internet voting does not ensure that voters cast their votes alone, the validity of internet voting must be demonstrated on other grounds.[19] To ensure that the voter is expressing their true will, they are allowed to change their electronic vote by voting repeatedly electronically during advance polls or by voting at the polling station during advance polls.[20] This mechanism ensures that the vote buyer or coercer will not know for sure which ballot will be eventually counted rendering vote buying or coercing meaningless.

Following concerns on secrecy and security, Estonian Electoral Committee has established a set of principles to which internet voting must adhere to. These principle comprise of the following:[21]

- **Time framework of I-voting**: I-votes may be given during 7 days, from the 10th day until the 4th day before the Election Day.

- **Possibility to recast I-vote**: during the I-voting period a voter can recast his/her I-vote in which case the last I-vote counts.

- **Precedence of the ballot paper voting**: if a voter who has already I-voted goes to the polling place during advance polls and casts his/her vote by using paper ballot, then the I-vote is cancelled. After that, the voter cannot recast his or her vote electronically or by using a paper ballot. On the Election Day the I-vote cannot be changed

[18] More detailed overview can be obtained from: http://vvk.ee/public/dok/General_Description_E-Voting_2010.pdf
[19] https://www.ndi.org/e-voting-guide/internet-voting
[20] Source and more information available at: http://vvk.ee/voting-methods-in-estonia/
[21] Retrieved from: http://vvk.ee/voting-methods-in-estonia/

- **Similarity of I-voting to regular voting**: I-voting adheres to the election acts, general election principles and customs. Thus, it is uniform and secret, only eligible voters may vote, every person may cast only one vote, it should be impossible for voters to prove the way they voted. The collecting of votes is secure, reliable and verifiable.

- **An I-voter shall vote himself/herself**. Using another person's ID card (or mobile-ID) for voting and transfer of the card's PIN codes to another person is prohibited. In order to avoid security risks, only a trusted computer should be used, either owned by the voter or a person the voter can trust.

The most recent and technologically advanced response to security concerns is vote verification. Piloted during local elections of 2013 and made compulsory from 2014 European elections onward, vote verification enables Estonian e-voters to verify whether their vote was cast as intended. Effectively, vote verification makes it possible to detect whether the computer is infected with malware that changes the I-vote or blocks the I-voting.

The process of vote verification involves the usage of a smart device (a smartphone or a tablet) equipped with a camera and Internet connection. After the voting process in the voting application a QR-code is displayed in the voting application and using a smartphone with a QR-code reader a vote verification app allows the voter to verify their vote. About 4% of all e-voters used vote verification in the last European Parliament elections in 2014.

Usage of e-voting in Estonia and impact on turnout

The spread of internet voting in Estonia follows a typical pattern of technology diffusion by which early periods of new innovations attract few enthusiasts, but as time passes, more and more users will opt for the new technology becoming eventually widely spread across the population.

Similarly to technology diffusion the growth of internet voters has not been instantaneous. Instead the share of e-voters in the first e-enabled elections was very low - only less than 2 percent of all votes were cast online. That is, every 50th vote was cast over the internet. However, this number has increased by about 4.3 percentage points with each succeeding election, reaching a all time high in 2014 where every third vote is cast online (refer to the linear regression coefficient in Figure 14).

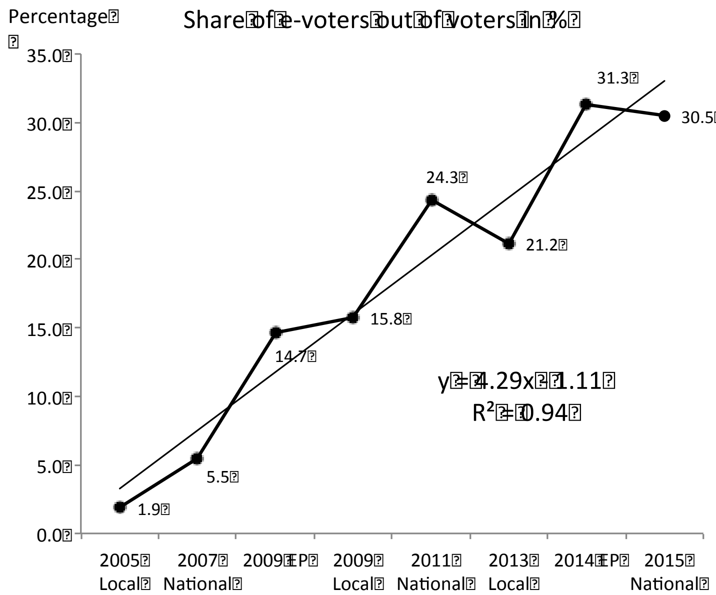

Figure 14. The share of e-voters out of all voters

There are two important policy implications to be highlighted on the experience of Estonian internet voting. First, unlike the practice and theory of technological innovations would prescribe, the growth of internet voting does not seem to follow an exponential, but a linear growth. Recall that in terms of the growth in digital-ID and X-Road queries, the growth turned exponential after slow pace in the beginning. Internet voting seems to be distinctive in this sense and therefore more rapid in its early stages.

However, this pattern of diffusion introduces a second policy implication. The growth of e-voters in spite of its rapidness as compared to other technological innovations still requires sufficient time before it starts to spread and appeal to the masses. In other words, due to its slow takeoff pace in the beginning governments adopting e-voting practices should not decide immediately after first few internet voting trials on whether or not continue to offer internet voting; whether it appeals to a homogenous subpopulation of technology enthusiasts or does it attract also voters that are less savvy with computers. Research has shown that at least three elections with internet voting are required before the new voting technology starts to diffuse among the electorate and engage voters of heterogeneous backgrounds.

Impact on turnout

When first pilots of internet voting where conducted in early 2000s, the implicit hope was that the modernization of voting technologies would counter the declining levels of voter turnout. In Estonia that argument has never been at the forefront of the political agenda in introducing e-voting. Rather, it was seen as an additional means to increase the convenience by which citizens can participate in political life and therefore constituted an extension of an already started motion in developing a modern e-governance. Indeed, in many ways participation in election over the internet manifests itself as an ultimate form of digital governance.

Still, it merits to investigate the turnout patterns in Estonian elections before and after the introduction of internet voting in 2005 in order to assess whether the turnout has changed or not. Because elections at different levels vary in terms of their salience and thus, turnout, we separate the turnout rates for the national, local and European elections and display their over time trends in Figure 15. Notice the reference line drawn to 2005 which was the first, when internet voting was introduced in Estonia.

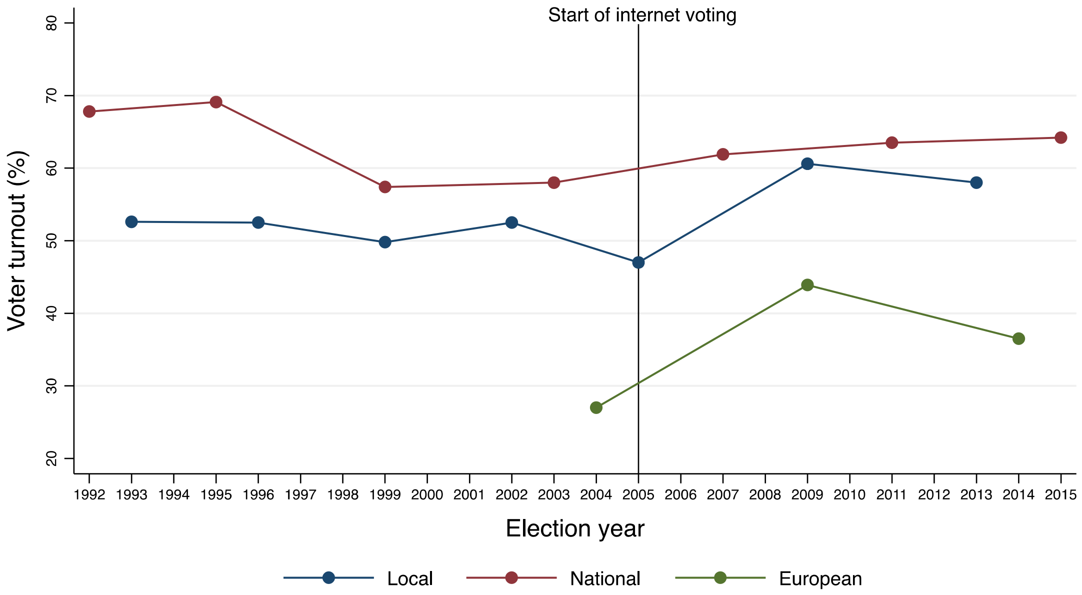

Figure 15. Turnout levels in Estonia, before and after the introduction of internet voting.

With respect to national elections the general trend until 2005 is a declining one. It has been often argued that the first formative elections since the restoration of independence were unusually high due to the high sense of political efficacy among the citizens and therefore the decline afterwards has been expectable. Yet, from the 2007 national elections, i.e., the first elections with an option of online voting, the turnout has incrementally, but steadily increased.

The same holds true for the local election with even more pronounced pattern. Unlike the national elections, the turnout in local elections was almost constant up until 2002 hovering at around 52%. Since 2005, however, the turnout level has jumped up about 10 percentage points.

Regarding the European Parliament elections we refrain from making any inferences. Primarily because we only have data on three elections and EP elections are clearly second-order in terms of saliency to electorates in Europe.

Taking these findings together we can clearly say that the turnout levels have improved after the introduction of e-voting in Estonia. However, we warrant caution in interpreting these findings in causal terms. It is not clear whether the modernization of voting technologies or some other relevant event or societal process has improved the levels of turnout.

Behavioral impact on internet voting and diffusion patterns

Following the elections in Estonia and using eight post-elections studies conducted after each e-enabled elections over the span of 10 years, academic research has reported three main behavioral outcomes that are strongly associated with internet voting and bear relevance from policy-making perspective. Summarizing these empirical findings in one sentence would yield the following:

> Internet voting in Estonia has diffused among the electorate because it considerably saves time and because people who start voting online rarely switch back to conventional voting.

Let us consider the diffusion of e-voting at first. Diffusion is a process by which people from different socio-demographic backgrounds (but also with varying attitudinal and behavioral profiles) adopt to new voting technology and at some point e-voters become very similar in terms of their background characteristics to those who vote by conventional means. In other words, diffusion of internet voting has taken place when the odds of e-voting are the same for the young and the old, for the PC-literate and the less computer savvy people and so on. That this is indeed the case has been partly shown in Figure 14, but more thoroughly by Vassil et al, 2014. An important policy implication, however, is that diffusion is not immediate, but requires at least three elections, after which greater heterogeneity among e-voters starts to appear. Therefore, e-voting should not be considered as a barrier to political participation excluding voters with certain characteristics form the political decision making. Quite contrary, in the long run internet voting has the capacity to bridge conventional societal divisions and bring the less resourceful closer to the politics.

The mechanism that induces the diffusion of internet voting has two founding elements. First, because e-voting is convenient and less time consuming than conventional on-paper voting, people who are required to spend considerable amount of time for visiting the ballot stations are likely to prefer internet voting. Prior research has shown that the threshold is measured by the time that is required for voting. In particular, if voting takes more than 30 minutes in total (including going to the ballot station and returning home afterwards) the probability to switch to online voting increases dramatically. Thus, internet voting helps rational people to reduce the cost that are required to partake in elections.

The second mechanism that helps internet voting to diffuse among the population is its ‘stickiness’. Solvak and Vassil (2014) have shown that internet voters in comparison traditional on-papers voters are very unlikely to ever go back to paper voting. More precisely, 85% of e-voters voted online also in the previous election. At the same time only 69% of on-paper voters remained on-paper voters. These suggest that internet voting is considerably more ‘sticky’ and thus habit forming facilitating further diffusion in the future.

5. Summary and recommendations for policy

Estonian e-governance is an intertwined ecosystem of institutional, legal and technological frameworks that jointly facilitate an independent and decentralized application development by public and private institutions to replace conventional public services with digital ones. In this report we explored its foundational components as well as fiscal and behavioral consequences. Our final task is to summarize the key components of Estonian e-governance system and provide a set of recommendations for best practices.

First, the most crucial components of Estonian e-governance are digital identification of citizens, a digital data exchange layer and ultimately, a layer of applications developed by different public and private institutions. Figure 16 summarizes the role and function of each of the components that constitute Estonia’s ecosystem of e-government.

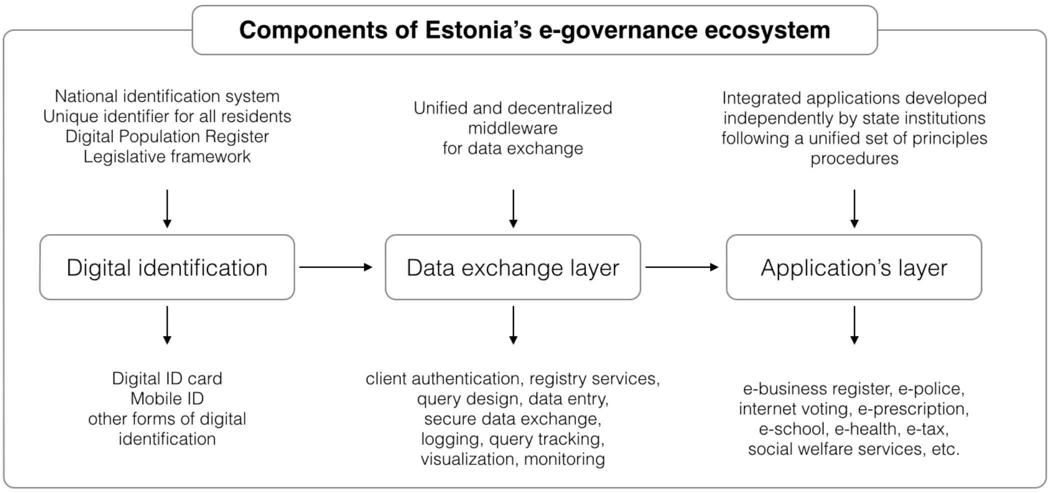

Figure 16. Estonia’s e-governance ecosystem

As argued in the first part of the report the most critical component of a functional e-governance system is the digital identification of citizens and residents. However, digital authentication in itself requires several institutional, legal as well as societal conditions. First, an institutional setup needs to address the issues of national identification system where a single numeric identifier is used for the entire population (instead of many based on various services). Second, personal data should be stored in a electronic data repository, by design similar to the Estonian Population Register. And finally, a normative environment should explicitly regulate the process by which institutions, individuals and companies can request and receive access to information stored in government databases.

The second functional component is the unified de-centralized data exchange layer that ensures standardized mechanisms for data gathering, structuring and storage; and subsequent application development. Moreover, an effective e-government would profit from a middle-ware system that would minimize, similarly to Estonian X-Road, repetitive data collection, interconnectedness of state's databases and avoids the labor-consuming processing of paper documents, data entry and verification.

Finally, when the digital identification and the data exchange layer are provided by the state, different institutions should be given an opportunity to develop their own extension of their services into the digital realm. Furthermore, if developed the ecosystem of eventual services will facilitate the growth in usage numbers. The latter will require a substantial amount of time, about 5-7 years in Estonian case. By implication it, countries should therefore not decide immediately after making first steps in e-governance about its efficiency and impact. As Estonian evidence shows it is only after first few years of intensive work that the growth in usage, efficiency and impact will surface.