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Cross-national analysis of the relation of eGovernment maturity and OSS growth

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ABSTRACT

The aims of this research are to explore and evaluate the nature of the relationship between open source software (OSS) and eGovernment maturity, as well as the factors impacting their development at a national level. The study proposes a theoretical framework, under the prism of which socio-economic, technological and institutional factors critical to eGovernment and OSS are revealed. The hypotheses are evaluated by means of an econometric model of simultaneous equations. In order to better gauge the results of the hypotheses, the model is evaluated over economic environments at different stages of development.

Social development and OSS growth were found to be the most important facilitators for eGovernment maturity, across countries of all stages of development. Institutional quality, technological openness, freedom in press and the macro-economic environment exerted different weights of importance across different country groupings. Findings also suggest that technological infrastructure and innovation are important drivers for OSS growth across countries at all stages of development. Research results can provide useful input for research in eGov, as they open up new directions in the study of the relation with OSS.

1. Introduction

Having realized the administrative potential of information and communication technologies (ICTs) for organizations, many governments around the world have adopted policies towards the use of ICTs in delivering improved services to citizens. This shift has led to the emergence of eGovernment (eGov). eGov refers to the transformation of traditional public sector services and processes into an electronic format with greater accessibility and interactivity to citizens (Huang and Bwoma, 2003).

As eGov implementation is continuously increasing among countries, an increasing interest in the study of the phenomenon has emerged. Research on eGov development and evolution across countries has showed that it should not be studied merely from a technological perspective. A number of researchers have identified different aspects of eGov's nature, such as social (Ho, 2002; Singh et al., 2007), economic (La Porte et al., 2001; Shareef et al., 2009), political and institutional (Azad et al., 2010; Wong and Welch, 2004; Ifinedo, 2011), organizational (Srivastava and Teo, 2010), cultural (Khalil, 2011), public administrative (Moon and Norris, 2005; Stamati and Karantjias, 2011) and behavioral (Shareef et al., 2009). Of course, these findings did not eliminate the importance of technological advancements and infrastructure for the eGov success (Singh et al., 2007; Azad et al., 2010; Relly and Sabharwal, 2009; Siau and Long, 2004). Ifinedo (2011) also showed that the greater the level of technological innovative capacity of a country, the higher its eGov maturity.

Taking another view of the technological innovativeness, Lakka et al. (2013) examined the impact of a special innovation, that is the widely diffused open source software (OSS). Free/open source software (F/OSS) is an innovative model of

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development and use of software, according to which software is produced through collaborative communities, while the source code is offered open for use, inspection modification and distribution with or without changes.

F/OSS introduces innovative methodologies for the design, development and maintenance of software. For example, the way of organizing and managing technological and human resources which support the software development process through organized communities of developers–users. It also introduces a new ideology and understanding of the software sharing, which gives a special emphasis on the collectiveness, cooperation and transparency in the development process (Von Hippel and Von Krogh, 2003; Stallman, 2002). As thus, many researchers have identified OSS as a successful open innovation paradigm (Von Hippel and Von Krogh, 2003; West and Lakhani, 2008; Von Hippel, 2001; Gächter et al., 2010).

In the context of eGov development, OSS shares the same notions and goals with eGov at its highest maturity levels, namely collectiveness, cooperation and transparency. These common values imply that OSS growth may create the appropriate ideological background and social conditions for eGovernment maturity. At the same time, eGov development could also affect OSS growth as well. OSS poses competitive advantages to organizations (such as cost reduction and interoperability) which make it more appealing to the public sector and an emerging technological trend into the context of eGov. This, in turn, could lead to higher diffusion of OSS as a basic component of eGov reform tools in public organizations and beyond.

Motivated by these findings, the aim of this research is to explore and evaluate the nature of the relationship between OSS and eGov, as well as the factors impacting their development at a national level. Though a number of studies have discussed the potential of OSS to e-democracy and public participation in emerging eGov systems (Hahn, 2002; Chadwick, 2003; Berry and Moss, 2006), very few have examined the relationship of eGov and OSS (Lakka et al., 2012, 2013) in the cross-national context. The latter studies, however, were limited to a small dataset of countries. What is more, no previous research was found to have explored the possibility of a simultaneity effect in the relation of the two concepts.

The study proposes a theoretical framework under which the relationship of eGov maturity with OSS growth and other critical factors is modeled. In order to better gauge the results of the hypotheses, the model is evaluated over economic environments of different stages of development. The study adds to the discourse of eGov by answering the following research questions:

- RQ1 What kind of theoretical framework could be used for the study of the relation of eGov and OSS?
- RQ2 Are there simultaneity effects in the relation of eGov development and OSS growth?
- RQ3 What other country level factors impact eGov development and OSS growth?
- RQ4 How does the impact of these factors vary across countries of different stages in development?

The remainder of the paper is structured as follows. Section 2 provides with more detail on the eGovernment concepts and outlines its relation to OSS. In Section 3 the theoretical background together with the derived hypotheses are presented. The methodology and data used in the empirical analysis are described in Section 4. Statistical analysis and discussion of the corresponding results are illustrated in Section 5. Finally, conclusions, limitations of the study and future research are provided in Section 6.

2. eGovernment and open source software

2.1. eGovernment maturity

Literature provides with different approaches in modeling the level of eGovernment development. In general, eGov models are built in a stage-wise manner from immature (one-way communication) to the mature (digital democracy), so that at the aggregate level technological and organizational sophistication is to be continuously added (Valdés et al., 2011; UN PAP, 2011).

However, not all of these models are able to provide with means of measurements that enable national eGov efforts to be compared. Moon et al. (2005) by a thorough literature review concluded in two major elements in the development of global eGov measures. One element represents the content, functions, and sophistication of official government websites (for instance, UN PAP, 2011; West, 2001; La Porte et al., 2002). The other element considers the overall enabling factors that promote development of eGov as well as societal readiness and utilization of eGov services (for instance, UN PAP, 2011; Kirkman et al., 2002).

This study adopts the United Nations (UN) Public Administration Programme (UN PAP) approach (UN PAP, 2011) for modelling eGov development. The approach considers a four stage model, according to scale of progressively sophisticated citizen services. eGov development is measured by the Web Measure Index (WMI). Countries are coded in consonance with what they provide online and the stage of eGov evolution they are presently in. The first stage is the *emerging presence* in which an official online government presence is established. The next stage, *enhanced presence*, corresponds to the provision of greater public policy and governance sources. The third stage is *transactional presence* and enables a two-way interaction between the citizen and his/her government. Finally, the *connected presence* stage is the most sophisticated level in the online eGov services, where the government encourages the participation of citizens and other stakeholders and actively solicits citizens' views on public policy, law making, and democratic participatory decision making. At this level, eGov services aim at the highest level of *transparency*, *participation* and *collaboration*.

For the purposes of this study, the measure of eGovernment maturity is the mean value of the WMI index of eGov development and the E-participation Index. E-participation is an index indicative of both the capacity and the willingness of the state in enhancing e-information, e-consultation and e-decision to citizens, in order to enable participatory processes and decision-making in public policy without social exclusion. The full reports containing more details on the methodology for the calculation of both the indices can be found in the UN's reports (UN eGov Global Reports).

It should be noted that the terms eGov development and eGov maturity are fundamentally the same, as they are both based on the WMI index. Yet, the measure of eGov maturity enhances the value of eGov development, as it not only captures the sophistication level of eGov, but also the willingness and capacity of the government to improve eGov services. Previous research has also utilized this combination as a measure of eGov maturity, e.g. Ifinedo (2011) and Srivastava and Teo (2007).

2.2. Relation of eGovernment and OSS

OSS is an innovative model of software development, where users may become developers without any restrictions or discrimination. OSS is marked by ideologies and values of collaboration and sharing, adopting a different value creation model, in which value is an outcome of collective intellect achieved through the OSS community (Von Hippel and Von Krogh, 2003).

The OSS production model provides with a number of advantages that are valuable to organizations and governments, like cost effectiveness (West and Dedrick, 2006; Gillen and Waldman, 2009), security and reliability (Feller and Fitzgerald, 2002), availability of OSS communities support (Lakhani and Von Hippel, 2003) and independence from software vendors. Due to its merits, OSS is increasingly gaining momentum into the public sector and large organizations.

Many governments are influenced by the changes in the software industry with the emergence of OSS. This, in turn, has affected their policy towards open source. A number of researchers have investigated the reasons that lead governments to OSS policies. The main reasons cited are the independence from software vendors, the compatibility and compliance with open standards, cost effectiveness, transparency and ability for customization, security and reliability, interoperability, and availability of OSS community support (Hahn, 2002; Comino and Manenti, 2005; Lewis, 2010; Maldonado, 2010; Wong, 2004; Ghosh, 2006; Allen and Geller, 2012). Some research identifies political reasons, that is, governments that want to exert the common values of their political philosophy with the OSS philosophy (Maldonado, 2010). Such values are transparency, democratic processes and inclusion of everyone in the participation in the political processes, etc.

Some governments opt for the initiation of OSS projects, or the production of in-house software projects with OSS philosophy. Others are limited to the use of OSS platforms and applications, like Linux, Apache and OpenOffice. The latter, however, include a decision to, which only reflects a decision based on price or product, not on the basis of support for OSS philosophies.

The different kinds of policies applied by governments are described by Lewis (2010), who conducted a survey that tracked governmental policies towards OSS. The survey did not count decisions by governments to use or purchase OSS. The survey identified four categories of OSS policies: research, mandates (where the use of open source software is required), preferences (where the use of open source software is given preference, but not mandated), and advisory (where the use of open source software is permitted). The majority of the projects were for R&D purposes and advisory. The result shows that most governmental OSS projects aim at in-house software and independence from software vendors. It can also be derived that governments prefer an advisory policy for OSS, that is they avoid to mandate its use.

At the same time, in-house software is usually used for the implementation of eGov projects. As most eGov projects target to a wide audience (citizens) and not to a limited number of users (e.g. employees), there is a greater need for open standards, interoperability and large scale licensing. OSS and the innovative model of copyleft license, offers economy savings of a large scale. Putting all these together, OSS seems to be the most appropriate solution for eGov projects. This conclusion is confirmed in literature (Birk et al., 2003; EU-Ministerial-Declaration, 2009; McDermott, 2010; Zissis and Lekkas, 2011). For instance, the EU-Ministerial-Declaration (2009) identifies the need for the use of open specifications and promotes OSS for use in eGov implementations, as it aligns with its technological and economic objectives.

However, apart from the economic and technological perspective, the EU declaration (EU-Ministerial-Declaration, 2009) makes also obvious references to OSS philosophy and values. These include: (i) *collaboration*, that is collaboration with businesses, citizens and other stakeholders, in order to develop user-driven eGovernment services, (ii) *reuse*, that is availability of public sector information for reuse, (iii) *transparency*, that is transparency of administrative processes, and (iv) *participation*, that is encouraging of stakeholders to involve in public policy processes. These four objectives, also constitute the philosophy of the OSS model.

Similarly, the goal of eGov at the highest stage of maturity (*Connected presence*) is transparent procedures that encourage citizens to participate in policy making. It can be deduced that mature eGov and OSS share some common aims and values. The question that arises is whether the OSS development model has an impact on eGovernment philosophy and goals of maturity stages.

Chadwick (2003) as well as Berry and Moss (2006) argue that F/OSS may contribute to e-democracy and public participation in emerging eGovernment systems. The open source projects are characterized by transparency in both source code and the development process. They are also characterized by collaboration, where OSS community members are encouraged to actively participate either as developers (by code submission), or as users (by submitting useful comments that improve the program's usability).

Also, during the last years, OSS philosophy has inspired a number of other forms of open initiatives that extend beyond software to include open access, open documents, open science, open education, open government, open innovation and more. Open government is defined as the governmental response to citizens' demands for information and services from government organizations (La Porte et al., 2002). In the context of eGov the notion of governmental openness has met wide acceptance among nations and has become closely related to one of its goals at the higher stages of development (Relly and Sabharwal, 2009). Recently the US government has introduced the open government initiative declaration, which focuses on the creation of a legal framework that will institutionalize the principles of transparency, participation, and collaboration into the culture and work of eGovernment (McDermott, 2010). Collaboration in this context is defined as a recursive process where citizens and federal institutions

cooperate in an intersection of common goals. The declaration contains principles (like accessibility, transparency and openness) and methodologies (like collaboration and sharing), that are also obvious references to open source. Many of these orders stand out as opportunities for open source developers, to demonstrate how the OSS development model can help the administration improve towards the two principles of collaboration and participation.

It can be deduced, that mature eGov and OSS can be related in a philosophical and technological manner. However, what is the nature of this relationship? Is it unidirectional, or bidirectional? This paper attempts to answer these questions in the following sections.

3. Theoretical framework and hypotheses

The theoretical framework conceptualizes a country as a socio-economic system within which eGovernment development occurs. The model is based on the idea that the forces of growth to an economic system comprise of institutional, endogenous and exogenous factors and is specified as:

$$eGov_{it} = F\left(X^{endog}, X^{exog}, X^{inst}\right) \quad (1)$$

where $eGov_{it}$ is the eGovernment maturity determined by the three vectors of factors relevant to endogenous growth (X^{endog}), to exogenous growth (X^{exog}) and institutional theories (X^{inst}), for each country i, at time t. In this sense, growth is not restricted to economic development, but includes social, institutional and technological aspects. More particularly, eGov maturity is viewed under the prism of three theoretical perspectives: endogenous, exogenous growth and institutional theories.

The proposed theoretical framework is able to reflect all of the different aspects of eGov' s nature, that is technological, social, economic, organizational, political and institutional. The three theories have also been used by previous studies, as a theoretical lens to identify critical factors for eGov development, as for instance Azad et al. (2010), Wong and Welch (2004), Ifinedo (2011), and Lakka et al. (2013).

Endogenous growth theory suggests that economic growth is generated from within a system as a direct result of internal processes (Romer, 1994) and not external, e.g. through trade. Moreover, the enhancement of a nation's human capital will lead to economic growth by means of the development of new forms of technology, as well as efficient and effective means of production. In the long run, growth depends on the discovery of new products or technologies in a few leading economies (Barro and Sala-i-Martin, 1997). The theory has been applied into the context of eGovernment in various studies (Ifinedo, 2011; Siau and Long, 2004; Lakka et al., 2013). Based on this theory the study considers three endogenous aspects of a country, namely technological, social and economical.

The first factor examined is OSS growth, which encompasses both a technological and social perspective. Warkentin et al. (2002) stressed on the role of ICTs in stimulating the advancement of eGov evolution from one stage to the next. Also Ifinedo (2011) showed that the greater the level of technological innovative capacity of a country, the higher its eGov maturity. From the technological perspective, OSS offers a number of solutions that are widely used on the web either as platforms, or applications.

In addition, OSS innovation model consists of values and ideas that align with the values and goals of eGov at the higher levels of maturity stages (as explicitly described in Section 2.2). OSS notions have created new ways of thinking and new perspectives in areas like software, education, research, government and many others, where “open” initiatives and their cohorts are continuously growing. As a result these new trends towards openness, collaboration and sharing form new attitudes, beliefs and ideas in society. From a societal perspective the acceptance of the OSS philosophy can create favorable conditions for the development of eGovernment.

Hypothesis H1. OSS growth has a positive impact on eGov maturity.

Taking a socio-economic perspective, the study considers the impact of social development as an influential factor for eGov maturity. The term social development encompasses the notions of the quality of human capital and the standard of living, which complies with the theoretical background of endogenous growth. The hypothesis is based on the assumption that social development is a necessary facilitating factor for the achievement of the cultural and political leaps among the four stages of the eGov maturity model (UN PAP, 2011). This hypothesis has also been also confirmed by previous research, e.g. Siau and Long (2004, 2006).

Hypothesis H2. Social development is a critical facilitator of eGov maturity.

Finally, the economic conditions of a country are explored. Previous research has also focused on this aspect. La Porte et al. (2001) found that a nation's wealth explains about 30% of the variation in the number of websites across national ministries, while Singh et al. (2007) found that GDP per capita is associated with eGov maturity mediated by advanced technological infrastructure.

Based on the findings of Moon et al. (2005), who characterized macroeconomic stability a “pushing” factor for eGov evolution, this study assumes that a country's macroeconomic environment could play a role on eGov maturity.

Hypothesis H3. Macro-economic environment can determine the eGov maturity levels.

Institutional theory attends to the deeper and more resilient aspects of social structure. It is the process by which these structures are maintained and reproduced. Structures and activities are modified towards isomorphism not only for economic motivations, but often for social, cultural, or political ends (Scott, 2004). The theory exhibits three main streams in the view of the institutions in society. They are rational choice theorists, who stress regulative elements (North, 1990); early sociologists, who favor normative elements (Parsons, 1990); and recently organizational sociologists and cultural anthropologists, who emphasize cultural–cognitive elements (DiMaggio and Powell, 1991; Scott, 2001).

In the case of technology, including eGov, the theory aims to explore the creation, design, and use of advanced technologies

that are bound up with the forms and direction of social order. The theory requires the focus on interaction between people and the technology, and the historical processes as social practices evolve. These social processes are executed by the interactions among actors or stakeholders such as unions, investors, shareholders, financial institutions, customers, intermediaries, suppliers, academic institutions, business associations, and social activists (Hoffman, 2001; Fountain, 2001).

Institutional theory has been extensively used as a theoretical lens for the study of electronic services in the public sector, e.g. Azad et al. (2010), Wong and Welch (2004), Ifinedo (2011), Welch et al. (2010), Kim et al. (2009), and Silva and Figueroa (2002). Also, Gil-Garcia and Martinez-Moyano (2007) indicate that, at the aggregate level, eGov has been adding more technological and organizational sophistication as a result of both institutional isomorphism and pressures from businesses, citizens, politicians, interest groups, and other stakeholders.

In the investigation of institutional factors in cross-national studies, Ifinedo (2011) studied the regional differences in the impact of political rights, civil liberty rights, regulation and effective governance. Azad et al. (2010) developed a model of e-Government diffusion using the governance institutional climate as represented via democratic practices, transparency of private sector corporate governance, corruption perception, and the free press. The results indicate that the level of development of national governance institutions can explain the level of eGovernment diffusion. Lakka et al. (2012) also found a positive impact of institutional quality on eGov development.

Taking into account the above research, this study opts for two particular institutional factors: institutional quality (IQ) and the free press. Firstly, IQ is chosen, as it encompasses most of the different institutional dimensions of a nation into a single index. As a result, it gives an overall overview of a country's institutional strength. The measurement of the IQ index is explicitly described in Section 5.

Hypothesis H4. Institutional quality plays an important role on eGov maturity.

Secondly, the institution of free press is also examined. One of the main eGov goals is to empower citizens by increased access to public information and strengthened transparency (EU-Ministerial-Declaration, 2009). However, the absence of free press is found to negatively influence citizens' perceptions of government transparency (Relly and Sabharwal, 2009). In addition, a number of studies (Relly and Sabharwal, 2009; Mendel, 2008) suggest that free press is critical to information dissemination and that access-to-information laws hold little value for citizens without free media. Previous studies have also examined the impact of free press (Azad et al., 2010) on eGov.

The hypothesis is that the absence of free press (as with transparency) eliminates citizen's trust and deters citizens from participating in governmental processes into the eGov context. Moreover, the free press plays a key role in sustaining and monitoring a healthy democracy. Thus, the absence of free press would negatively influence eGov maturity, where e-democracy and increased participation are important elements.

Hypothesis H5. Free press is a critical factor for eGov maturity.

Exogenous growth theory is grounded on the neoclassical growth model and the works contributed by Robert Solow (1956). It also assumes that growth is primarily determined by external factors, such as the flow of goods, ideas, capital and technology innovations, rather than internal factors. The theory states that a steady economic growth rate can be accomplished with the proper amounts of the three driving forces: labor, capital and technology and that when a new technology becomes available, labor and capital need to be adjusted to maintain growth equilibrium. Solow's model states that investment in capital alone cannot drive long run growth in GDP, while technological change is necessary to avoid diminishing returns to capital.

Under the prism of this theory, a country's openness can be perceived as the external force that captures knowledge spillovers among countries (Grossman and Helpman, 1991). In general, openness can be defined as the degree to which a country is open to business and economic influences through trade activities. A number of studies consider trade as a channel for the transfer of technological knowledge (Rivera-Batiz and Romer, 1991). The study assumes that a country's technological openness can leverage eGov adoption among countries and considers ICT trade as the channel for achieving such spillovers.

Hypothesis H6. A country's technological openness positively affects eGov maturity.

3.1. Hypothesis of simultaneity

In order to study the existence of simultaneous effects in the relation of eGov maturity and OSS growth, a simultaneous equation model is used. Simultaneous equations are actually a system of two or more econometric equations. This method serves the purpose of the study, as it not only tests the simultaneity effect, but also it evaluates the impact of other variables on both OSS and eGov on the same time. The simultaneous equation model is defined by the following system of simultaneous Eq. (2).

$$\begin{aligned} eGov_{it} &= F\left(X^{endog}, X^{exog}, X^{inst}\right) \\ OSS_{it} &= G(eGov_{it}, Y) \end{aligned} \tag{2}$$

G is a function of $eGov_{it}$ and a vector Y of all the explanatory variables relevant to OSS growth. The two equations in Eq. (2) are examined simultaneously, in order to test for the reverse causality between eGov and OSS. The conceptual model corresponding in Eq. (2) is graphically illustrated in Fig. 1.

H1 states that OSS is expected to affect eGovernment maturity. The hypothesis of simultaneity, as described by equations in Eq. (2), indicates that OSS growth is also affected by the eGovernment maturity, leading to a simultaneous relation of impact.

As already discussed in Section 2.2, OSS is especially promoted for eGov implementations by many countries for two main reasons. Firstly, it provides with competitive advantages, such as technological capacity and cost effectiveness that are particularly appealing to governments. In the context of eGovernment, OSS also offers the advantages of open

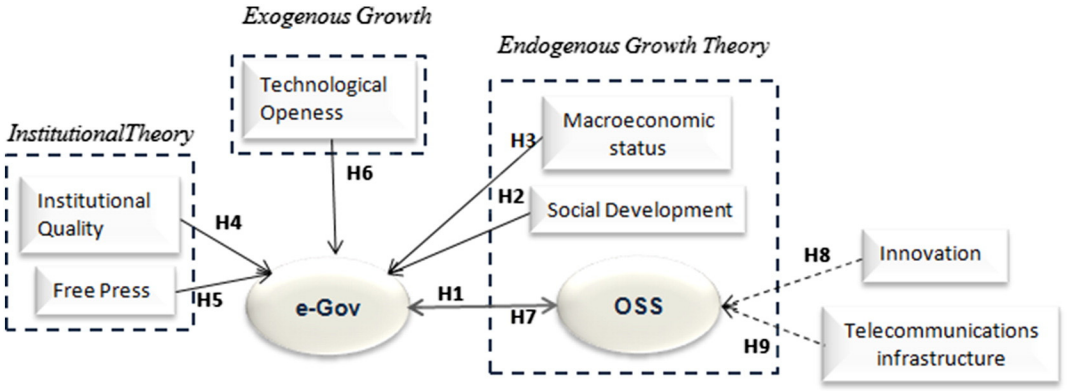

Fig. 1. Conceptual model.

specifications and standards, interoperability, large scale licensing, and independence from software vendors. Thus, OSS aligns to the technological and economical aims of eGov. Secondly, OSS philosophy and principles of participation, collaboration and transparency align to the goals and the principles of eGovernment at the higher levels of its maturity stages.

On the other hand, governments are in a unique position in almost any industry. By the nature of their immense size and influential position, their actions may have far-reaching effects. In the field of software, the programs used by a governmental agency often have a distinct advantage compared to unused programs. Software that is used becomes the de facto standard when dealing with that agency — if, indeed, it is not mandated. In addition, to its own usage, the thousands of government contractors are also forced to adopt the government's software platform of choice, so they are eligible to work for them. When all of these factors are considered, it becomes clear that the government plays a major role in determining the fate of the software industry, whether they intend to or not. Even the lack of an official policy is, in a sense, an action.

Putting these facts together, the increased utilization of OSS into eGov projects, is expected to expand OSS use to other organizations and individuals and consequently, positively affect its diffusion and growth.

Hypothesis H7. There is a simultaneous effect in the relation of eGov maturity and OSS growth.

Although OSS has become the objective of extensive research, studies that investigate the factors that influence its diffusion at a national level are quite limited. Therefore, there is little knowledge on the possible factors for OSS growth. The choice of the appropriate constructs was mainly based on the nature and characteristics of OSS.

Firstly, OSS is an innovation model of software production that rapidly evolves due to the ability of OSS communities to follow often and short release cycles. This innovative nature of OSS presupposes technology skilled and qualified human capital with willingness to create and innovate.

Numerous studies have characterized OSS as a form of open innovation (Von Hippel and Von Krogh, 2003; West and Lakhani, 2008; Von Hippel, 2001; Gächter et al., 2010; Dahlander and Gann, 2010; Spaeth et al., 2010). Chesbrough (2003) defines open innovation as "a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as firms look to advance their technology". Implicit in this definition is the need for organizations to collectively engage in sharing and exploiting valuable ideas. The OSS community is a large common pool of external free-of-charge resources that are fungible in different software product lines.

Organizations have recognized the strategic value of being "open" and realized that this effective process needs to be incorporated in the way they innovate that is, they need to acquire ideas and resources from both the internal and external environments (Chesbrough, 2003). By becoming "open", organizations can harness external and internal ideas to jointly advance their technologies: ideas and resources flow collectively in and out of organizations (Dahlander and Magnusson, 2008).

This close relationship of OSS and open innovation, leads to the conclusion that OSS communities will be larger in population and more active in countries with higher innovation.

Hypothesis H8. Increased innovation capacity is probable to affect OSS growth.

Secondly, telecommunication infrastructure such as the Internet and broadband connections, are vital not only for the growth, but also for the existence of OSS. This is due to the fact that its development model is totally based on virtual teams and remote management and collaboration. Thus, it is expected that the wide use and implementation of telecommunication infrastructure would positively affect OSS growth, as well.

Hypothesis H9. Telecommunications infrastructure is critical for OSS growth.

4. Methodology and data description

The study evaluates the hypotheses set in Section 3 by means of an econometric analysis of simultaneous equations across different economic environments. The econometric models are described in Section 5. The models are evaluated

using panel data analysis. The advantage in panel data is that data are studied over multiple years, thus a greater variation of data changes and behavior is captured, compared to the results produced by a single year study (i.e. cross-sectional analysis).

The dataset captures annual observations in 90 countries for the years 2003–2005, 2008 and 2010, over a period of eight years. The participating countries were selected from different regions, in order to reflect different economic status. The countries have been selected based on the stages of development as defined by the Global Competitiveness Report (GCR) (WEF).

In line with the economic theory of stages of development, the GCR report assumes that in the first stage, the economy is factor-driven and countries compete based on their factor endowments, namely primarily unskilled labor and natural resources. As a country becomes more competitive, productivity will increase and wages will rise with advancing development. Countries will then move into the efficiency-driven stage of development, when they must begin to develop more efficient production processes and increase product quality. The report categorizes countries into three main and two transition groups: stage 1, stages 1 to 2, stage 2, stages 2 to 3 and stage 3. Two criteria are used to allocate countries into the different stages of development.

The first is the level of GDP per capita at market exchange rates. This measure is used as a proxy for wages, because internationally comparable data on wages are not available for all countries covered. The thresholds for each stage are respectively (i) less than 2000, (ii) from 2000 to 3000, (iii) from 3000 to 9000, (iv) from 9000 to 17,000 and (v) more than 17,000. The second criterion measures the extent to which countries are factor driven. This is measured by the share of exports of mineral goods in total exports (goods and services), assuming that countries that export more than 70% of mineral products (measured using a five year average) are to a large extent factor driven.

For the purpose of this study 90 countries (out of 136 in the GCR) were selected in order to (i) include geographical regions from all continents, (ii) data for the different variables of the econometric model are available. The 90 countries are categorized into three development stages as follows: the first development stage contains 30 countries extracted from stage 1 and stages 1 to 2 of the GCR, the second stage includes 30 countries from stage 2 and stages 2 to 3 of the GCR and the third stage of development consists of 30 countries that were derived from stage 3 of the GCR. The countries and the development stage they belong to are presented in Appendix 1.

In order to find out differences among the three groupings, the models defined by Eqs. (1) and (2) were applied in each of the groupings, as well as in all 90 countries. Thus, four models were evaluated and compared.

In order to strengthen empirical results, this research has tried to use as many number of countries, as possible. However, collecting large scale primary data from ninety countries is constrained by the amount of resources available for conducting such a research. Hence, secondary data from reliable data sources like the World Bank (WB), the United Nations Development Program (UN) and the World Economic Forum (WEF) were extracted. The data sources are presented in detail in Table 1. The table illustrates all of the variables used in the econometric model, accompanied by a brief description of their content. Descriptive statistics for the corresponding dataset are provided in Table 2. Finally, some additional explanations on the

Table 1
Data labels, definitions, measurements, and sources.

Labels	Constructs	Measurements	Sources
Endogenous growth theory variables $-X^{endog}$			
OSS	*OSS* users reflected by the cumulative number of subscribed per country users in the SourceForge portal.	Natural log	OSS research portal
HDI	*Social development* is reflected by the Human Development Index. Higher values indicate better social conditions.	Values between 0 and 1	Klugman
MI	Macro-economic status is represented by the Macro-economic Index. Higher values indicate higher status.	Expressed in a scale from 1 to 7.	WEF
Exogenous growth theory variables $-X^{exog}$			
ICT_trade	*Technological openness is reflected by ICT goods trade. That is* calculated by the ratio of exports plus imports of ICT goods. These include telecommunications, audio and video, computer and related equipment; electronic components; and other information and communication technology goods.	Percentage of total goods trade.	World Bank Indicators
Institutional theory variables $-X^{inst}$			
IQ	*Institutional quality* corresponds to the mean value of the six dimensions of governance.	Measured in units ranging from -2.5 to $+2.5$.	Shareef et al. (2009)
FP	*Free press* is measured by the Freedom of the Press index, as estimated by the Freedom House's press freedom project. Lower values indicate higher freedom in press.	Measured on a scale from 0 to 100.	Freedom House
Factors impacting OSS growth $-Y$			
eGov	Average of the web presence Index and the E-participation Index.	Measured in the range of 0 and 1.	United Nations eGovernment-data center, UN eGov Global Reports
bband	Technological infrastructure is represented by the number of broadband subscribers. That is subscribers with a digital subscriber line, cable modem, or other high-speed technology.	Natural log	World Bank Indicators
innov	Charges for the use of intellectual property	Natural log	World Bank Indicators

Table 2
Descriptive statistics of the dataset.

Variable	Obs	Mean	Std. dev.	Min	Max
eGov	450	0.37	0.23	0.00	1.00
OSS	450	6.91	2.47	0.00	13.21
HDI	433	0.71	0.16	0.23	0.94
IQ	450	0.35	0.87	−1.50	1.90
FP	450	41.97	23.36	8.00	96.00
MI	404	4.50	0.86	2.49	6.62
ICT_trade	431	15.03	15.99	0.00	91.28
bband	427	11.95	3.45	0.00	18.65
innov	355	19.80	2.75	7.72	25.78

operationalization of the exploratory variables are provided in the following paragraphs.

As already explained in Section 2.1, the dependent variable, eGovernment maturity, is reflected by the average of the WMI and E-participation indices. OSS penetration is measured in terms of the cumulative number of subscribed users/developers in the SourceForge.net (2012) portal. The websites' large activity ensures that the distribution of registered users in different countries can be used as a proxy for the OSS users in each country. The SourceForge records over 300,000 open source projects and 3.4 million of registered users with more than 850,000 activities. For the year 2010 (used in this study), there were found approximately 2,750,000 registered users. Statistically, this can be an effective sample of the population. SourceForge as a data source has been extensively used in a number of studies for OSS, e.g. Chengalur et al. (2010). The process of deriving the number of SourceForge registered users is explicitly described in Appendix 2.

Social development is operationalized through the *Human Development Index* (HDI) of the UN Development Program (UNDP) Human Development Reports. HDI was created to serve as a frame of reference for both social and economic development and is a composite index of life expectancy, educational attainment and income. The education component of the HDI is composed of the mean of years of schooling for adults aged 25 years and the expected years of schooling for children of school going age. The standard of living component is measured by Gross National Income (GNI) per capita (PPP US$). More information on the index estimation can be found in the relevant reports (Klugman).

Macro-economic environment is captured by the Macro-economic Environment Index of the WEF Global Competitiveness Reports. The index is based on a mix of hard data as well as survey of executives and indicates the state of macro-economic condition of the country. It consists of three major components: macro-economic stability, institutional investor country credit rating and government waste. More information on the components of the index can be found in the corresponding reports (WEF, 2011). Other researchers have also utilized this data source for eGov development, e.g. Srivastava and Teo (2010).

A country's *institutional quality* is measured by means of the World Governance Indicators (WGI). The project reports on six dimensions of governance for each country: (i) voice and accountability, that is, the level of the citizens' ability to participate in processes like selecting their government, (ii) political stability and absence of violence, which reflects the likelihood that the government will not be destabilized or overthrown, (iii) government effectiveness, that is, the quality of public services, the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government, (iv) regulatory quality, that is, policies and regulations that permit and promote private sector development, (v) rule of law expresses the confidence and coherence to the rules of society, the police, the courts, as well as the likelihood of crime and violence, and (vi) control of corruption reflects the control over situations where public power is exercised for private gain. More information on the data and methodology can be found in the relevant reports (Kaufmann et al., 2010). The data have been previously used by a number of scholars in order to proxy the country-level institutional strength, e.g. Martinez (2010).

Innovation is reflected by the "charges for the use of intellectual property" indicators of the World Bank (World Bank Indicators). The indicators contain information on the sum of payments and receipts between residents and nonresidents for the authorized use of proprietary rights (such as patents, trademarks, copyrights, industrial processes and designs including trade secrets, and franchises) and for the use, through licensing agreements, of produced originals or prototypes (such as copyrights on books and manuscripts, computer software, cinematographic works, and sound recordings) and related rights (such as for live performances and television, cable, or satellite broadcast). Data are in the current U.S. dollars. The indicators consist of elements that are indicative of the level of the innovation activity in a nation. For instance, Barro and Sala-i-Martin (1997) showed that the absence of intellectual property rights across economies would lead to insufficient incentives to invent and an excessive incentive to copy. This, in turn would lead to a decrease in innovation activity.

Table 3
Correlation matrix.

	eGov	*OSS*	*HDI*	*IQ*	*FP*	*MI*	*Trade*	*bband*	*innov*
eGov	1								
OSS	0.654	1							
HDI	0.633	0.583	1						
IQ	0.631	0.415	0.682	1					
FP	−0.545	−0.401	−0.552	−0.705	1				
MI	0.296	0.177	0.318	0.368	−0.105**	1			
Trade	0.393	0.273	0.307	0.322	−0.157**	0.1857	1		
bband	0.529	0.861	0.642	0.411	−0.355**	0.2095	0.3012	1	
innov	0.526	0.826	0.632	0.461	−0.310**	0.2706	0.3861	0.724	1

Notes. All significance levels are at the $p = 0$ level, except where denoted by ** = $p < 0.05$.

5. Statistical analysis

All the statistical tests and calculations were derived with the STATA software. The data were initially checked for possible correlations among the participating variables. The correlation matrix is illustrated in Table 3. It can be observed that the variables *bband* and *innov* are highly correlated (significant at the $p = 0$ level) with the OSS variable, but they are not included in the econometric model given by Eq. (3). All other correlations were lower than 80%, the criterion level suggested by Kennedy (2003).

To test whether the maturity of eGov initiatives across the three different stages of development (illustrated in Appendix 1) compares over time, the nonparametric tests of Mann–Whitney and Wilcoxon were performed. The tests were carried out to determine whether statistically significant differences exist between a pair of different stages of the sample countries. The results presented in Table 4 indicate that eGov maturity significantly differs in each pair of stages.

As a result, the following econometric equation (Eq. (3)) was performed for each stage of development, in order to determine the kind of impact of the hypothesized factors for each group of countries separately. Eq. (3) is derived by Eq. (1) and the hypotheses stated in Section 3.

$$eGov_{it} = a + b_1 OSS_{it} + b_2 HDI_{it} + b_3 MI_{it} + b_4 ICT\_trade_{it} + b_5 IQ_{it} + b_6 FP_{it} + u_i + \varepsilon_{it} \quad (3)$$

for each country i and year t. Also, u_i is the country specific effect and ε_{it} is the idiosyncratic error.

If there is simultaneity between OSS and eGov, then OSS should be an endogenous variable of the above regression. A variable is endogenous, when it is correlated with the error term. Simultaneity is another form of endogeneity and arises when one or more of the explanatory variables is jointly determined with the dependent variable, each of them having a ceteris paribus, causal interpretation (Wooldridge, 2002). If simultaneity exists then both the dependent and explanatory variables are correlated with the error term, thus are endogenous.

Endogeneity of OSS is tested by the Durbin–Wu–Hausman (DWH) test under the null hypothesis that OSS is exogenous. The results for each model are illustrated in Table 5.

All models show evidence of endogeneity, except for the case of the country group that belongs to the first stage of development (Model 2), where the hypothesis of simultaneity effect is rejected. For the rest of the country groupings, the simultaneous effects between eGov and OSS can be further evaluated by means of the model of structural equations in Eq. (4).

$$\begin{aligned} eGov_{it} &= a + b_1 OSS_{it} + b_2 HDI_{it} + b_3 MI_{it} + b_4 IQ_{it} \\ &\quad + b_5 ICT\_trade_{it} + b_6 FP_{it} + \nu_{it} \\ OSS_{it} &= c_0 + c_1 innov_{it} + c_2 bband_{it} + c_3 eGov_{it} + \mu_{it} \end{aligned} \quad (4)$$

where $\nu_{it} = u_i + \varepsilon_{it}$ and μ_{it}, are the error terms of each equation, respectively. In the case of endogeneity, as well as simultaneity, the most applicable econometric method is the use instrumental variable (IV) estimation and the two stage least squares method (2SLS). However, the 2SLS results are valid, provided that the selected instrumental variables are also valid. More particularly, the instruments should be: (i) uncorrelated with the error term, (ii) uncorrelated with the rest of the exogenous variables, and (iii) correlated with the endogenous variable *OSS*. Table 3 shows that the variables *bband* and *innov* satisfy (ii) and (iii), and thus could be selected as candidate instruments. The selected instruments are further validated with the appropriate tests, as follows.

The Sargan (1958)–Hansen (1982) test is a test of over-identifying restrictions. The joint null hypothesis is that the instruments are valid instruments; that is uncorrelated with the error term. Secondly, the underidentification test is a test of whether the equation is identified. A rejection of the null hypothesis indicates that the matrix is full column rank; that is the model is identified. For heteroskedastic, AC, HAC, or cluster–robust statistics, the LM and Wald versions of the Kleibergen and Paap (2006) rk statistic are used.

Another test is of weak identification. This arises when the excluded instruments are correlated with the endogenous regressors but only weakly. Estimators can perform poorly when instruments are weak, and different estimators are more robust to weak instruments. In the case of non-i.i.d. errors, the robust statistic is the Kleibergen–Paap Wald rk F-statistic. As a rule of thumb, the F-statistic should be at least 10 for weak identification not to be a problem (Staiger and Stock, 1997). Finally, the significance of the endogenous regressors can be tested with the Anderson and Rubin statistic, which is robust to non-i.i.d. errors, as well. The null hypothesis indicates that the coefficients of the endogenous regressors in the structural equation are jointly equal to zero.

Table 5 illustrates the results of the above statistical tests that validate the use of *innov* and *bband* variables as instruments for the endogenous variable *OSS*, in all three models (Model 1, Model 3, Model 4).

Next, two post-estimation tests for serial correlation and heteroscedasticity for the panels were performed. Results for all models are illustrated in Table 5. As shown in Table 5, the Wooldridge (2002) test for autocorrelation in panel data, showed evidence of serial correlation in the idiosyncratic errors in all models (the null hypothesis is no first order autocorrelation). On the contrary, the Pagan and Hall's (1983) test for heteroskedasticity for instrumental variable (IV) estimation, showed that disturbances are heteroscedastic only for the case of Model 1 (all 90 countries). According to Wooldridge (2002), the modern approach to IV estimation is based on the principle of generalized method of moments (GMM), especially in the case of autocorrelated and heteroscedastic errors. Thus, the optimal method for the case of these models is 2SLS feasible generalized method of moments (GMM estimator) with

Table 4
Non-parametric tests.

Comparisons	Mann–Whitney	Wilcoxon
Stage 1–stage 2	16,366.50	10,872
Stage 1–stage 3	12,735	11,317
Stage 2–stage 3	16,215	10,759.50

Note: all of the results are significant at the $p = 0$ level.

Table 5
Statistical tests for each model.

Statistics	Model 1	Model 2	Model 3	Model 4
Instrumental variable validity tests				
Sargan/Hansen	$\chi^2(1) = 0.72$ $p = 0.39$	NA	$\chi^2(1) = 0.74$ $p = 0.102$	$\chi^2(1) = 0.97$ $p = 0.32$
Kleibergen–Paap rk F	116.09	NA	48.93	59.83
Kleibergen–Paap rk Wald	$\chi^2(2) = 238.38$ $p = 0$	NA	$\chi^2(2) = 105.46$ $p = 0$	$\chi^2(2) = 127.86$ $p = 0$
Kleibergen–Paap rk LM	$\chi^2(2) = 37.29$ $p = 0$	NA	$\chi^2(2) = 45.13$ $p = 0$	$\chi^2(2) = 48.059$ $p = 0$
Anderson–Rubin F	$F(2,300) = 17.24$ $p = 0$	NA	$F(2,103) = 12.51$ $p = 0$	$F(2,117) = 15.87$ $p = 0$
Statistical tests for each model				
Endogeneity	$\chi^2(1) = 6.24$ $p = 0.01$	$\chi^2(1) = 0.02$ $p = 0.86$	$\chi^2(1) = 10.3$ $p = 0$	$\chi^2(1) = 12.9$ $p = 0$
Serial correlation	$F(1,67) = 95.13$ $p = 0$	$F(1,9) = 133.63$ $p = 0$	$F(1,24) = 10.3$ $p = 0$	$F(1,26) = 52.19$ $p = 0$
Heteroscedasticity	$\chi^2(7) = 16.3$ $p = 0.02$	$\chi^2(2) = 494.07$ $p = 0$	$\chi^2(7) = 6.29$ $p = 0.5$	$\chi^2(7) = 10.7$ $p = 0.15$

heteroscedasticity and autocorrelation (HAC) consistent standard errors for Model 1, and with AC consistent standard errors for Models 3 and 4.

For the case of Model 2, where no IVs are necessary, both the modified Wald test as performed by Greene (2000) for groupwise heteroskedasticity and the Wooldridge (2002) test for autocorrelation in panel data, showed evidence of heteroskedasticity and serial correlation, respectively. Thus, the optimal method choice for Model 2 is the feasible generalized least squares (FGLS). FGLS assumes strict exogeneity of the independent variables and provide results consistent for HAC errors. GLS is equivalent to applying OLS to a linearly transformed version of the data, which requires minimizing. Thus, just as the OLS estimates measure the marginal impact of each of the independent variables on eGov, so do the FGLS estimates (Wooldridge, 2002).

Finally, regression results for each of the models are presented in Table 6.

5.1. Discussion of results

Table 6 indicates that there is a positive and statistically significant effect of OSS growth on eGov maturity at $p < 0.001$ level, in all four models. Consequently, Hypothesis H1 is verified.

Table 6
Regression results.

Theories	Hypotheses	Variables	Model 1	Model 2	Model 3	Model 4
			All countries	Countries in stage 1	Countries in stage 2	Countries in stage 3
Endogenous growth	H1	*OSS*	0.04 (0.006)***	0.024 (0.005)***	0.05 (0.01)***	0.066 (0.013)***
	H2	*HDI*	0.26 (0.101)***	0.243 (0.07)***	0.34 (0.13)***	0.046 (0.022)***
	H3	*MI*	0.022 (0.018)*	0.012 (0.023)	0.026 (0.012)*	0.025 (0.023)
Institutional	H4	*IQ*	0.05 (0.02)***	0.019 (0.026)	0.024 (0.037)	0.035 (0.013)**
	H5	*FP*	−0.06 (1.223)	−0.014 (0.007)*	−0.002 (0.003)	−0.004 (0.007)
Exogenous growth	H6	*ICT_trade*	0.023 (0.009)***	0.053 (0.134)	0.015 (0.018)	0.005 (0.001)***
		constant	−0.582 (4.956)	−1.527 (1.801)	−0.63 (2.629)	−1.511 (1.821)
		R^2	0.89	NA	0.87	0.93
		F	$F(6,301) = 45.53$	Wald $\chi^2(6) = 65.01$	$F(6,104) = 23.08$	$F(6,118) = 32.09$
		N	308	112	111	125
		:	Regression method 2SLS GMM	Regression method FGLS	Regression method 2SLS GMM	Regression method 2SLS GMM
Simultaneity	H7	*eGov*	0.25 (0.13)***	NA	1.62 (1.71)***	0.746 (0.432)***
	H8	*innov*	0.41 (0.099)***	NA	0.45 (0.08)***	0.242 (0.082)***
	H9	*bband*	0.37 (0.07)***	NA	0.14 (0.07)***	0.683 (0.10)***
		constant	−4.61 (1.28)***	NA	−3.82 (1.26)**	−3.81 (1.73)***
		R^2	0.98	NA	0.98	0.98
		F	$F(3,304) = 89.7$	NA	$F(3,107) = 43.09$	$F(3,121) = 55.42$
		N	308	NA	111	125
		Regression	2SLS GMM	NA	2SLS GMM	2SLS GMM

Notes.

- The numbers are the regression coefficients, with the standard error in parentheses.
- NA = Not available.
- Significance levels are denoted by: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

This, in turn, proves that OSS growth is a critical factor for eGov maturity and that its importance is not eliminated across different economic environments.

The higher coefficient (0.066), however, is achieved at countries of the third stage of development (Model 3). Countries with higher development typically are more technologically advanced and innovative and thus are more likely to experience higher OSS penetration and consequently OSS growth. This assumption complies with the findings of the econometric model, where both technological advancements and innovation were found to be critical factors for OSS growth (H8, H9).

On the other hand, reverse causality of the relation could not be supported by the results. The model of simultaneity was applied in all but one country groupings, that is, countries belonging in the first stage of development. In this case H7 was immediately rejected for statistical reasons, as indicated in the previous section. However, an impact of eGov maturity on OSS growth could not be found in any of the rest of the country groupings, as well. The results reject Hypothesis H7 of the simultaneity effect. As shown in Table 6, eGov maturity is not significant in any of the models. It can be deduced that OSS growth is not influenced by the maturity of eGov initiatives.

This may be due to a limited utilization of OSS into the context of eGov, even at the more mature levels. Though OSS seems ideal for in-house programming and platform use, many governments are still skeptical in its wider use at an end-user level. In many cases, it is preferred a mixed strategy, with the use of both proprietary and OSS. The reasons for this skepticism, relies mainly on the fact that complete migration to OSS solution entails risks in terms of total cost of ownership and long term sustainability of the software. For instance, the support of the OSS product will be vanished, if the OSS community behind this product stops to exist. For critical governmental procedures, such risk could not be undertaken. However, this risk is eliminated when OSS is used for in-house programming and the software can be sustained by the "in-house" software team. The problem that many governments have to face with, is the lack of in house skills required to implement and sustain OSS projects. As for instance there are still few OSS projects (Thakur et al., 2014).

On the other hand, OSS has reached high maturity levels of diffusion during the last years. Thus, the part of OSS growth that could be attributed to eGov, is far too less compared to other influencing factors. As a result, it might be too early for studying a simultaneous impact. For instance, in Model 1, the statistical significance of eGov on OSS was very close to acceptable ($z = 1.92$, $p = 0.06$).

On the contrary, OSS is much more affected by telecommunication infrastructure, like broadband penetration (0.37, at $p = 0$ for Model 1, 0.14, at $p = 0.03$ for Model 2 and 0.68 at $p = 0$ for Model 4), which remains a sustainability factor. The same applies to a country's innovation levels (0.41 and 0.45 significance at $p = 0$ for Models 1 and 3 respectively, 0.24 at $p < 0.01$ for Model 4) verifying that OSS and innovation growth follow parallel trajectories. Thus hypotheses H8 and H9 are both confirmed for all models. Results could not be evaluated for Model 2, as the simultaneous equations were not applied.

Another critical factor for eGov maturity proved to be social development. Except for Model 4, social development has the highest coefficients of the regressions (0.26 for Model 1, 0.24 for Model 2 and 0.34 for Model 3). The coefficient in Model 4 (0.046) is ranked after the coefficient of OSS growth. What is most important, however, is that in all four models social development exerts a high impact, verifying Hypothesis H2. This draws upon the importance of social structures and development conditions such as the living standards and education attainment, for the achievement of cultural and political leaps among the different stages of eGov development.

Of particular interest are also the findings for the rest of the factors impacting eGov maturity and how their impact differs across the three stages of development. Firstly, the macroeconomic index was found to be statistically significant only for Model 2 (stage 2 of development). In general, a nation's macro-economic conditions don't prove to affect eGovernment maturity, as the factor exhibited no statistical significance ($p > 0.05$) in Model 1, which includes all of the 90 countries.

Thus, the macro-economic environment plays an important role on stage 2 countries only. This is quite rational, as stage 2 includes developing countries that pursue economic growth and development and thus most actions and initiatives, such as eGov initiatives, are closely related to this endeavor. On the contrary, for the countries that are at the initial and upper stage of development, economic conditions do not affect eGov maturity levels.

Secondly, institutional quality, is especially important in developed countries (stage 3 of development) with statistical significance at $p < 0.01$. In these countries institutions, like the effectiveness of the government to exercise power, enact laws and regulations, etc. can play an important role on the implementation of eGov initiatives and consequently on eGov maturity. On the contrary, countries at the earlier stages of development do not seem to be affected by institutions (significance: $p > 0.05$).

However, in the general Model 1 of the whole sample, institutional quality shows evidence of a positive impact on eGov maturity (coeff = 0.05, at $p < 0.05$). It can be concluded, that overall, institutional quality is an influencing factor for eGov maturity, as Model 1 includes countries from different economic environments, while Models 2 and 3 apply to countries with common characteristics and as thus conclusions cannot be generalized. On that ground, Hypothesis H4 can be accepted. The result comes in accordance with previous research that found significant impact of institutions on eGov maturity.

Based on the same rationale, the institution of Free Press is not an influencing factor for eGov maturity and thus Hypothesis H5 is rejected. Free Press was not found statistically significant in Model 1 and the same applied for Models 3 and 4. However, quite interesting is the importance of Free Press for countries that are at the early stage of development. As shown in Table 6, Free Press is significant at the $p < 0.05$ level (coeff = −0.014), where the negative sign of the coefficient is due to the Free Press Index (FPI) scale, i.e. the lower the FPI value, the higher the freedom in press. Thus, it is shown that Free Press can have a positive effect on eGov maturity in early stage developing countries. On the

contrary, for the rest of the countries Free Press is not a facilitating factor.

Finally, technological flows and spillovers expressed by ICT trade show a positive and significant relationship with eGovernment in the general Model 1 ($p < 0.01$) and Model 3 ($p = 0$). Since ICT trade is significant in Model 1, Hypothesis H6 is confirmed. This, in turn implies that ICT trade and the free exchange of knowledge and ideas can diffuse technological and ideological eGov implementations and actions from one country to another, resulting in an enhanced Government maturity.

It can also be concluded that ICT trade does not add to the eGov maturity levels in developing countries (non-significant). This may be explained by the fact that in these countries, ICT trade may not have yet reached high enough levels to enable the transfer of the required ideas, which will influence eGov initiatives. On the contrary, in the developed countries which exhibit higher rates of exchange, eGov maturity is significantly influenced by ICT trade. Results are summarized diagrammatically in Table 6.

6. Conclusions

The research contributes to the eGov and OSS research by the creation of a parsimonious model that examines the simultaneity effects between eGov maturity and the growth of the innovative open source software. The model was developed under the prism of the theories of institutionalism, endogenous and exogenous growth. The model also reveals the impacting factors for eGov maturity and OSS growth and how these factors behave across countries at different stages of development.

Results indicate that the proposed theoretical framework can be successfully deployed for the study of eGovernment and OSS across different countries (RQ1). In addition, the hypothesis that OSS growth has a severe impact on eGov maturity has been confirmed in all of the different country groupings. OSS encompasses both a technological and ideological aspect. It is based on the notions of collaboration, sharing and transparency that have created new trends and initiatives such as open government, open content and open education. Similar to these trends, eGovernment goals at the higher levels of maturity, also include transparency, collaboration and participation of the citizens. The result complies with the hypothesis that OSS and eGov though different in nature, have strong similarities and aligned perceptions.

However, although the above considerations imply that there is a mutual causal effect in their relationship, reverse causality has not been confirmed by the results (RQ2). This means that OSS growth constitutes to the development of eGov, but OSS growth does not depend on eGov development. The result may be due to the fact that OSS solutions have not yet been extensively incorporated in the eGov initiatives, even at a mature level. The benefits of OSS are significant and many governments have recognized their importance. Yet, the extent of these benefits has been limited because of a combination of the skills requirements of OSS projects and the policy environment in which these projects develop.

Nevertheless, the fact that there is a close relation between eGov and OSS, should put practitioners into thinking of the utilization of OSS not only in a technological manner, but also as an organizational paradigm in terms of openness, collaboration, democratization and participation of citizens. The concepts and development methods that derive from the OSS innovative model of production, could enhance transparency, enable higher participation in eGov initiatives and ultimately improve electronic services. Practitioners could turn to OSS with a primary focus on benefits that can be derived from the OSS philosophy and translation of OSS approaches to management that emulate OSS style and governance practices.

Such policy would probably lead to a wider utilization of OSS and consequently increase OSS popularity and ultimately OSS growth. Based on this rationale, the simultaneity effect could be in place, if this policy is applied by government officials.

Regarding the third research question, findings suggest that social development is one of the most critical factors determining eGov maturity. Its impact was found significant across countries of all stages of development. From the citizen's perspective, the use of electronic services presupposes that they have the willingness to do so. Thus, the levels of social development in a country, such as standards of living and education can help create perceptions and culture with a positive attitude towards eGov initiatives. At the same time, institutional quality in terms of effective governance, regulation, law, corruption, democratic processes and political stability, showed a significant impact on eGov maturity, especially in developed countries.

It can be concluded that social processes and concepts are fundamental for the maturity of electronic services. The institutional factors indicate the maturity or willingness of the government to implement eGov initiatives, while social development is the measure of maturity or willingness of the society to accept such initiatives.

In addition, a country's technological openness can positively affect electronic services. The free exchange of knowledge and technological spillovers create favorable conditions for the diffusion of technological and ideological eGov implementations and actions from one country to another, resulting in an enhanced Government maturity.

Another interesting finding is the difference of the weight of impact of the various factors across different economic environments (fourth research question). For countries that are under development, IQ was not found a significant factor. This could be attributed to the fact that institutions in these countries may be insufficient and defective and as thus are not able to significantly influence eGov services. The same applies for technological openness, which has an impact only in developed countries (stage 3). Again, this may be due to the lower rates of ICT trade for countries of stages 1 and 2, which are inefficient to transfer technological knowledge.

A country's macro-economic environment, on the other hand, was found significant only for developing countries of stage 2. This, in turn, leads to the conclusion that economic conditions are quite critical for developing countries of that stage, which in turn may be able to influence other aspects of national endeavors, such as the eGov initiatives. The same rationale applies for the institution of Free Press. The latter was found to be significant only for countries that are at the

very early stage of development (stage 1). As with the rest of their institutions, countries at this stage may lag behind in transparency, democracy and freedom in press. Governments that exert restrictions in press and transparency are very improbable to have the willingness to facilitate democratic and participatory decision making to citizens, leading to lower levels in the eGov maturity model.

Moreover, the econometric analysis revealed two critical factors for OSS growth: technological infrastructure and innovativeness. The factors were found to be highly significant in all stages of development. Thus, they can be considered as important enablers of OSS growth. This is quite expected as technological infrastructure, such as the Internet and broadband, is absolutely important for the existence of OSS. OSS development model is based on the existence of the web infrastructure and services.

Quite interesting are the findings about the close relationship of OSS and innovation, which show that the growth of OSS is positively related with a country's innovation rates. The results suggest that there is an important impact of open innovation practices and the private-collective model of innovation introduced by OSS communities in a country's innovation performance. OSS communities are a large pool of knowledge, ideas and resources that promote innovativeness and creativity (Von Hippel and Von Krogh, 2003; Von Hippel, 2001), while at the same time, OSS introduces open innovation practices that are acknowledged and adopted by many firms and organizations.

The research findings could be used as helpful input for both research and practice. For research, they introduce the idea of a causal relationship between OSS and eGov. This opens up a wider discussion on the influence of OSS and its principles on eGovernment, as well as on other open initiatives, such as open government, open education and open innovation. As thus, it calls for a deeper understanding of the social, technological or institutional mechanisms that underlie this impact.

For practice, the research sheds light on the impacting factors for eGov maturity, as well as how this impact varies across countries from different stages of development. This information is quite useful for policy makers that want to evaluate the eGov maturity potential within a country. Moreover, implementation of eGov initiatives requires substantial reform in public organizations. The successful OSS development model introduces open methods and practices that may prove to be key solutions for the effective implementation of processes into the context of eGov.

6.1. Limitations and future research

One of the limitations of this study is the use of secondary data for the operationalization of the construct's measures. However, collecting large scale primary data for ninety countries is constrained by the amount of resources available for conducting such a research. As a result most of the research on cross-national level is based upon secondary data. The latter, create the need for further validation of the data used. In order to ensure that the best possible sample was deployed, the study used a dataset based on the following criteria:

(i) Reliable data sources. Data from official organizations like the WB, the United Nations Development Program and the WEF were explored and used. These data are the result of scientific research. Most of the produced data are accompanied by scientifically sound reports, where a thorough analysis of their derivation, validity and calculation is presented. Moreover, this kind of data is extensively used by governments and authorized organizations as official data. Finally, they are widely used by researchers in well known Scientific Journals.

(ii) Rationale that comply with the construct's rationale. The operationalization of constructs should be based on rational arguments that prove the similarities of the construct and its measure.

(iii) Operationalizations made by previous research. Some measures have been widely used by researchers for the operationalization of some concepts (e.g. trade for openness and knowledge transfer).

(iv) Statistical validation. The choice of the variables used in the econometric model should comply with statistical rules. For instance independent variables should not be correlated between them, also the choice of IVs in the simultaneous equation model has a number of restrictions. Though some other measures might seem more reasonable to be used, the statistical tests as described in Section 6, hindered their use.

Another problem is the existence of missing values in the dataset. The aim of the study was to use as many countries as possible. However, data sources do not always provide datasets without omitted values. The statistical production of missing data was avoided, as its extensive use could lead to statistical bias. That is why the number of countries was limited to 90, where most of the data were available. In this way missing values were few and STATA was able to produce the results without any inherent bias.

This study introduces the issue of the causal relationship between OSS and eGov. The findings of this study open up a discussion on the direct and the indirect impact of OSS to eGovernment and call for a deeper understanding of the processes and events that underlie this impact. A number of research question arise. For instance how and to what extent can the common values of collaboration, transparency and participation determine the relation of OSS on eGov? Should research focus on technological, social or even political causes for the existence of this relationship? Interpretive and case studies could shed more light on this issue.

The deeper understanding of these mechanisms could also shed light on the simultaneity effects in the relation of eGov and OSS. Though, simultaneity was not confirmed by this study, the close relationship and the common values and perceptions of eGov and OSS create the need for a better justification and deeper understanding underlying this relation. Moreover, the issue of simultaneity effect could be revisited in the long run, when eGov initiatives will have reached higher maturity levels and/or OSS implementations into the eGov context will have increased.

In line with the above, research could also focus on a possible impact of OSS on other open initiatives, such as open government, open innovation, open education and more.

Appendix 1. List of countries for each development stage

	Stage 1	Stage 2	Stage 3
1	Algeria	Argentina	Australia
2	Armenia	Bahrain	Austria
3	Bolivia	Barbados	Belgium
4	Botswana	Bosnia and Herzegovina	Canada
5	Brunei Darussalam	Brazil	Cyprus
6	Burundi	Bulgaria	Czech Republic
7	Egypt, Arab Rep.	Cape Verde	Denmark
8	Gambia, The	Chile	Finland
9	Guatemala	China	France
10	India	Colombia	Germany
11	Indonesia	Costa Rica	Greece
12	Iran, Islamic Rep.	Croatia	Ireland
13	Jamaica	Ecuador	Israel
14	Kazakhstan	Estonia	Italy
15	Kuwait	Hungary	Japan
16	Libya	Jordan	Korea, Rep.
17	Madagascar	Malaysia	Luxembourg
18	Mauritania	Mauritius	Malta
19	Mongolia	Mexico	Netherlands
20	Mozambique	Oman	New Zealand
21	Nigeria	Panama	Norway
22	Pakistan	Peru	Portugal
23	Paraguay	Poland	Singapore
24	Qatar	Romania	Slovenia
25	Rwanda	Russian Federation	Spain
26	Saudi Arabia	South Africa	Sweden
27	Tanzania	Thailand	Switzerland
28	Ukraine	Tunisia	United Arab Emirates
29	Venezuela, RB	Turkey	United Kingdom
30	Zambia	Uruguay	United States

Appendix 2. Derivation of OSS data

The OSS users are reflected by the SourceForge registered users. SourceForge is the world's largest OSS development website, with the largest repository of OSS code and applications available on the Internet, offering free services to developers. It is owned by Dice Inc. (formerly owned by OSTG Inc.). The website is database driven and the supporting database includes historic and status statistics on projects and user activities. Dice has shared certain SourceForge.net data with the University of Notre Dame (UND) for academic and scholarly research purposes.

UND receives monthly data from the SourceForge database, which are processed and stored in a new database (BND). The UND has adequately designed BND database in a PostgreSQL environment, in order to be able to easily retrieve the required information. The data used for this paper were extracted from the UND's platform (OSS research portal) under written permission. The UND provides an online platform (http://srda.cse.nd.edu/cgi-bin/form.pl), where registered users can extract data by applying the relevant SQL queries.

The disadvantage of UND's online system is that it has high response time, especially in cases of complex queries. For this reason, a local database (B_{SL}) was created by the authors in order to locally store some of the BND tables. B_{SL} was designed according to the BND relational database model. This would help eliminate response time of the network connection and allow experimentation and data processing. Schematically, the process of data extraction is illustrated in Fig. A1.

As it is shown, the data downloaded from the BND database were in a .txt or .xml format. The data were the result of simple SQL queries (e.g. SELECT * FROM *sf1210.users*) and corresponded to the December of 2010 SourceForge data. Although the .xml files enable better structure, the .txt files were downloaded much more quickly, so they were preferred when there were numerical data, or more straightforward field structure. Finally, the downloaded files were imported in the B_{SL} database in appropriately preformed tables.

The number of registered SourceForge users for each country, was derived by the table *users*. Its structure is presented in more detail in the following table.

Table 7
Structure of table users.

user_id (PK)	Integer	Not null
user_name	Text	Not null
realname	Character varying (32)	Not null
status	Character (1)	Not null
unix_uid	Integer	
add_date	Integer	Not null
people_resume	Text	Not null
timezone	Character varying (64)	
language	Integer	Not null
cf_uid	Integer	
stay_anon	Integer	
donation_request	Text	
donate_optin	Integer	
last_sitestatus_view	Integer	
row_modtime	Integer	

The field *user_id* is a unique identification number for each user and is used as a primary key (PK). The field *timezone* contains the geographical location of users. In order to find the

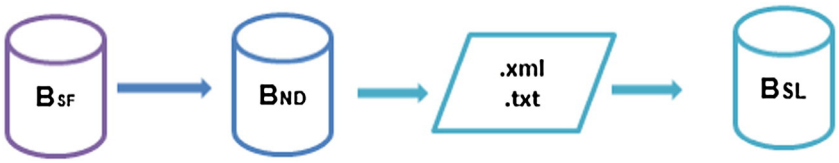

Fig. A1. Data extraction from B_{ND} database.

number of users for each location sorted by the year of registration, the following query was applied:

SELECT COUNT(user_id) AS users, timezone, YEAR(DATEADD(s, add_date, CONVERT (DATETIME, '1970-01-01 00:00:00', 102))) AS year

FROM s1210.users

GROUP BY timezone, YEAR(DATEADD(s, add_date, CONVERT(DATETIME, '1970-01-01 00:00:00', 102)))

ORDER BY year

Where, the field *add_date* corresponds to the user's date of registration. The field was in numerical format and transformed in a date format with the DATEADD function. Most of the records register the capital city of a country. However, some records also list the country's largest city, or even the name of the country. In order to find the number of users for each country, all of these options were used. For instance, in order to find the number of registered users in Greece, the following query was applied:

SELECT timezone, users, year

FROM users_by_timezone_year

WHERE (timezone IN ('%Athens%', '%Greece%', '%Thessalon%'))

ORDER BY year

where, *users_by_timezone_year* is the name of the first query. The last query was applied for every country separately. Results were aggregated in order to retrieve the cumulative number of OSS users over the years 1999–2010.

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