# Cross country comparison on the factors determining OSS diffusion


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## ABSTRACT

The aim of this paper is to investigate and evaluate the critical factors that underlie the Open Source Software (OSS) diffusion among countries. Grounded on a theoretical framework of diffusion of innovations theory and the theories of institutionalism, endogenous and exogenous growth, the study proposes a parameterized diffusion model that evaluates the weight of impact on two stages of the OSS diffusion: the initialization stage and the diffusion's growth rate. Research findings stress on the importance of innovation, the quality of human capital, the technological infrastructure, the protection of intellectual property and knowledge spillovers among countries, at all stages of the diffusion process.



## General Terms

Management

## Keywords

Open Source Software, diffusion of innovations theory, socio-economic factors, innovation


## 1. INTRODUCTION

OSS is an innovative model of software development, where software is open for inspection, modification and exchange without restrictions or discrimination. As a result OSS has special characteristics that create value on both the users and developers side. Due to its merits, diffusion of OSS has been radically increased into most of the software market sectors. Although the OSS phenomenon has become the objective of extensive research, the studies that provide a thorough analysis on its global diffusion and the national level factors that shape this diffusion, are still quite limited.

Past research on the critical factors that affect OSS adoption has focused mainly at individual, group, and organizational level of analysis [1-8]. A limited number of studies examine the adoption factors at a national level [9-12], while some of them are not supported by theoretical foundation or empirical data. Nevertheless, the international nature of OSS technology poses some challenges for decision makers that wish to be informed on details of the OSS diffusion process, such as timing of growth and factors that affect this process.

Taking into account this gap in the literature, the study uses diffusion of innovation theory (DOI) as a lens to conceptualize the diffusion process and establish a set of factors that are expected to influence its shape. The impacting factors were further analyzed and derived under the prism of three socio-economic theories: the exogenous growth, the endogenous growth and the institutional theories. The factors were evaluated at different stages of OSS diffusion, by means of a modification of the Bass diffusion model [13]. The model has been proposed by Dekimpe et al. [14] and it parameterizes variables that may affect the diffusion growth.

The study aims to address the following research questions. What theoretical foundation can be used to identify country level factors that affect OSS diffusion? What are the impacting factors? What is the impact of these factors at different stages of the diffusion process?

The rest of the paper is organized as follows. In section 2 the theoretical framework is presented. Section 3 sets the hypotheses, constructs and their measures. The description of the OSS diffusion model and the empirical dataset are illustrated in Section 4. Discussion of results is presented in Section 5, while overall conclusions, limitations and future research are included in Section 6.

## 2. THEORETICAL FRAMEWORK

DOI theory has been introduced by Rogers [15] as the "process by which an innovation is absorbed by a social system". It is widely used to describe the process of the diffusion of innovations through a social system, seeking explanations in terms of "how" innovations diffuse through it, by the means of appropriate mathematical models, the so called diffusion models.

Although the diffusion path of most innovations can be represented in the general S-shaped fashion, different types of innovations can result in different evolutionary pattern, depending on the effects of factors closely related to the social system. More recently, several IS researchers have pursued an understanding of the significant factors at play throughout the diffusion process across countries, e.g., [16-19]. Kraemer et al. [17] and Wolcott et al. [19] reported that economic and financial resources, regulatory and legal policy and framework, and information infrastructure influence cross-country diffusion of e-commerce and the Internet respectively.

In order to further analyze the factors of the social system affecting diffusion, this study proposes three socio-economic theories: the exogenous growth, the endogenous growth and the institutional theories. The proposed theories have been widely used in Information Systems research to explain growth of technological innovations across countries, e.g [20-22]. In addition OSS is not merely a technological innovation. It entails a social perspective, where OSS users and developers constitute a community that carries specific norms, values and ideologies. As a result, socio-economic perspectives perfectly align with OSS multidimensional nature.

*Endogenous Growth Theory* suggests that economic growth is generated from within a system as a direct result of internal processes [23; 24] and not external, e.g. through trade. In the long run, growth depends on the discovery of new products or technologies in a few leading economies [25]. *Exogenous Growth Theory* is grounded on the neoclassical growth model and the works contributed by Robert Solow [26]. It assumes that growth is primarily determined by external factors, such as the flow of goods, ideas, capital and technology innovations, rather than internal factors. *Institutional Theory* was introduced by Scott [27] and 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.

The theoretical framework conceptualizes a country as a socio-economic system within which OSS growth 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:

$$OSS_{it} = F(X^{endog}, X^{exog}, X^{inst}) \qquad \textbf{(1)}$$

Where $OSS_{it}$ is the OSS growth rate 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.

## 3. HYPOTHSES, CONSTRUCTS AND MEASURES

The hypotheses set under the prism of the theoretical framework of the three socio-economic theories, as described in section 2, as well as the OSS special characteristics and previous research in diffusion of technological innovations. The constructs and their measures are summarized in Table 1.

*Endogenous growth theory factors ($X^{endog}$).* The factors that stem out of this theory include the technological infrastructure, the quality of human capital, the innovation activity and the economic growth status of a country.

*Telecommunications infrastructure,* such as the Internet and broadband connections, is a key element not only for the diffusion but also for the existence 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 H1**).

Infrastructure is measured by the number of broadband subscribers as registered by the World Bank database [28]. That is subscribers with a digital subscriber line, cable modem, or other high-speed technology.

On the same time, *human capital* is recognized as a key input to the development of knowledge, new ideas and products associated with technological progress. Prior studies demonstrate that the average level of education [29] and the quality of human capital [30] are influential drivers for individual technology adoption. In addition, a number of studies [1; 11] showed that skilled and experienced users are more probable to adopt OSS, as its complexity becomes an inhibitory factor. It can be deduced that human capital skills and education would have a positive impact on OSS growth. (**Hypothesis H2**).

In order to measure a country's quality of human capital, the study adopts the Human Capital Index (HCI). The index relies on the United Nations Development Program (UNDP) [31] 'education index' which is a composite of the *adult literacy rate* and the combined *primary, secondary and tertiary gross enrolment ratio* with two third weight given to adult literacy and one third to gross enrolment ratio.

Prior studies have identified the close relationship between OSS and *innovation* [32; 33]. The growth of OSS is mainly due to the large number of skilled and qualified developers with willingness to create and innovate. Thus, OSS is not only an innovative technology, but also is a continuous source of innovation. Therefore, it is assumed that a country's innovativeness will be a 'pushing' factor for the growth of OSS (**Hypothesis H3**).

Innovation is reflected by the "charges for the use of intellectual property" indicators of the World Bank. 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) and related rights (such as for live performances and television, cable, or satellite broadcast). The indicators consist of elements that are indicative of the level of the innovation activity in a nation. For instance, Barro [25] 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 innovations activity.

**Table 1. Hypothesis, constructs and measures**

| **Construct** | **Measure** | **Variable name** |
|---|---|---|
| ***H1:****Telecommunications infrastructure* measured by the number of broadband subscribers [28]. | Natural log number | BBS |
| ***H2:*** *Education and Human capital* measured by the HCI [31]. | Ranged in [0, 1] | HCI |
| ***H3:*** *Innovation* measured by "charges for the use of intellectual property" indicators [28]. Data are in current U.S. dollars. | Natural log number | INNOV |
| ***H4:*** *Economic growth* measured by | Natural | GDP |

| | | |
|---|---|---|
| GDP per capita [28] | log | |
| ***H5:*** *Technological openness* measured by ICT trade [28]. | Natural log | ICTtrd |
| ***H6:*** *Policy regarding trade* is measured by the regulatory trade barriers index [34]. | Ranged in [1,10] | RTB |
| ***H7:*** *Policy for the protection of property rights* is measured by the Protection of property rights index [34] | Ranged in [1,10] | IPR |

*Economic growth*. Previous research has showed that economic growth is directly related to technological growth (e.g. [20; 25]). Although OSS can be acquired at low or zero price, the study tests the possibility that economic development of a country creates demand for more technologically advanced products such as OSS. Economic growth is reflected by GDP per capita at market exchange rates. This measure is used as a proxy for economic growth in most of the relevant studies. (**Hypothesis H4**).

*Exogenous growth theory factors ($X^{exog}$).* Under the prism of this theory, a country's openness can be perceived as the external force that captures knowledge spillovers among countries [35]. 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 [36]. The study assumes that a country's technological openness can leverage OSS adoption among countries and considers ICT trade as the channel for achieving such spillovers (**Hypothesis H5**). ICT trade is calculated by the ratio of exports plus imports per GDP of ICT goods. These include telecommunications, audio and video, computer and related equipment; electronic components; and other information and communication technology goods [28].

*Institutional theory factors* ($X^{inst}$). The quality and operation of institutions may have a severe impact on the way that social systems behave towards a technology. As a result a large number of studies focused on institutionalism as a prism for the interpretation of technology adoption [20; 37-39]. Governments have the opportunity to intervene and take actions affecting the markets and the dissemination of new technologies. This study examines the impact of government's regulations and policies in two sectors which were assumed to affect OSS diffusion. That is innovation (hypothesis H3) and trade (hypothesis H5). More particularly, the study examines the impact of regulation in trade, which would create trade barriers and in intellectual property rights, which would inhibit innovation activity [25]. (**Hypotheses H6 and H7**)

Operationalization of the two constructs is based on two indices of the Economic Freedom Network (EFN) [34] that is created by the Fraser Institute for research purposes. EFN has members from 80 countries and uses 42 metrics from 141 nations. Data are widely used in many scientific studies (e.g. [20]). *Policy regarding trade* is measured by the regulatory trade barriers index, that is Non-tariff trade barriers and compliance cost of importing and exporting. Their goal is the economic freedom of the world. *Policy for the protection of property rights* is measured by the Protection of property rights index. That is the exclusive authority to determine how a resource is used, whether that resource is owned by government or by individuals. If the resource is owned by the government, the agent who determines its use has to operate under a specific set of rules. Higher values indicate higher quality.

# 4. MODEL DESCRIPTION AND DATA

## 4.1 OSS Diffusion Model

The diffusion model used for the study of cross-country OSS diffusion, is the model proposed by Dekimpe et al. [14] and which is a modified Bass model [13]. The Bass diffusion model suggests that a new product adoption decision is driven by two factors: coefficient of external influence, the influence that is independent of the existing number of adopters, and coefficient of internal influence, the social influence of the existing number of adopters. The model specifies that the likelihood that an individual will adopt a new technology at time *t* given that he has not yet adopted, is a linear function of the number of existing adopters:

$$h(t) = \frac{f(t)}{1 - F(t)} = p + qF(t) \qquad \textbf{(2)}$$

where *h(t)* is the hazard rate of the likelihood to adopt at time *t*, given that no adoption has occurred in the time interval *(0, t)*. *f(t)* and *F(t)* denote the probability density and cumulative density function at time *t*. *p* and *q* are the coefficients of external and internal influence respectively. Expressed in terms of the aggregate number of adopters, equation (2) becomes:

$$n(t) = \left(p + \frac{q}{m}N(t)\right)(m - N(t)) \qquad \textbf{(3)}$$

Where *n(t)=mf(t)* is the number of adopters at time *t, N(t)* is the cumulative number of adopters at time *t* and *m* is the market potential.

According to Dekimpe the Bass model limits comparison of diffusion parameters across countries for two reasons. First, the Bass model uses a time series of number of adopters to estimate the diffusion parameters. As a result, a small and a large country that have exactly the same number of adopters over time will have the same diffusion parameters. This implies that the two countries, without considering their sizes, share the same diffusion pattern, which may not necessarily be correct. Second, by using fixed time periods for all countries in a data set, there is higher risk of left-hand truncation bias where the estimates of the intercept of the diffusion curve are inflated for those countries that start their adoption process earlier than the time frame represented by the data.

To address these limitations, the modified Bass model for a country *i* was proposed as [14]:

$$n_{i,t} = \left[\left(\frac{n_{i,1}}{C_i S_i}\right) + B_i\left(\frac{N_{i,t-1}}{C_i S_i}\right)\right]\left[C_i S_i - N_{i,t-1}\right], t = 1, 2, \ldots k \qquad \textbf{(4)}$$

where $n_{i,t}$ is the number of adopters at time *t*, $N_{i,t-1}$ is the cumulative number of adopters up to time *t-1*. $S_i$ is the social system size, $C_i$ is the long-run penetration ceiling. $B_i$ is the diffusion growth rate. The diffusion curve intercept $(n_{i,1}/S_iC_i)$ is also referred to as parameter $A_{i1}$.

It should be noted that parameters $A_{i1}$, $B_i$, and $C_iS_i$ are similar to parameters *p*, *q*, and *m* in the Bass model. Although the modified Bass model was designed to examine overall diffusion process, it is flexible enough to estimate state-based diffusion parameters by limiting observations to those defined by diffusion states of interests. Also, two logistic models test covariates that affect the first year adoption ($A_{i1}$) and diffusion growth rates ($B_i$):

$$A_{i,1} = [1 + e^{d_1 X_i}]^{-1}$$
$$B_{i,t} = [1 + e^{d_2 X_i}]^{-1} \quad \textbf{(5)}$$

where $d_1$ and $d_2$ are vectors of parameters and $X_i$ is the vector of the covariates for country ***i***.

For the case of the OSS diffusion model the vector of covariates $X_i$ that is tested for its impact on the two diffusion states includes the covariates described in section 4.1 and is defined as:

$$Xi = (GDP, BBS, HCI, INNOV, ICTtrd, RTB, IPR) \quad \textbf{(6)}$$

The impact of the covariates is evaluated using non-linear econometric model as defined by equations (5) and (6). The rest of the model's parameters are defined as follows.

The social systems are populations in a country and the long-run penetration ceiling is defined as the maximum proportion of the population that will adopt. Factors that govern the dynamics of social systems and long-run penetration ceiling are exogenous to a technology. The model requires matched sampling of the first two parameters $(C_iS_i)$ and the alignment of introduction timing of an innovation across countries for valid comparisons of the cross-country diffusion parameters.

**Social system size $S_i$** is assumed each country's population. This is quite rational as the diffusion of OSS is considered at a country level. It is also an approach followed in most of the studies, e.g [14; 40].

**Long-term penetration ceiling $C_i$** is defined as a proportion of the population that has an intrinsic utility and thus will adopt the technology. For instance the population subset aged between 0 and 5 years will not probably adopt OSS, or be registered users in SourceForge. As a result, the study considers $C_i$ as the proportion of the population aged between 15 and 65, as this age range should include the majority of OSS users.

**Alignment of introduction timing of OSS**: The model sets time *t=1*, the first year of adoption of each country, so that all countries' diffusion will set off from a common point of the time axis.

## 4.2 Empirical Dataset

The analysis is based in data from 25 countries over the period 2003-2008. The countries were selected so that to reflect different regions and economic status. More particularly, there were 13 countries from Europe (Belgium, Finland, France, Germany, Greece, Italy, Netherlands, Spain, Sweden, United Kingdom (UK), Romania, Russia, Turkey), 5 countries from America (Argentina, Brazil, Canada, Mexico, United States (US)), 5 countries from Asia Pacific (Australia, China, India, Japan, Korea) and 2 countries from Africa (South Africa, Tunisia).

As already discussed in section 4.1, constructs are based on secondary country level data and are presented in Table 1. OSS penetration is measured in terms of the cumulative number of subscribed users/developers in the SourceForge.net portal [41]. 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. For the year 2009, there were found approximately 2,750,000 registered users. Statistically, this can be an effective sample of the population. SourceForge has shared certain data with the University of Notre Dame (UND) for academic and scholarly research purposes. Our study relies on data extracted from the UND's platform [42] under written permission. The number of users is calculated by querying the UND's database for the aggregate number of users, for each country.

Data for the $C_i$ parameter were derived by the World Bank database [28] and the indicator 'population ages 15-64, % of total'. Data for the $S_i$, *parameter* were extracted by the United Nations (UN) database [43] and the indicator 'Total Population'.

# 5. RESULTS AND DISCUSSION

First year penetration is directly calculated by $A_{i,1} = n_{i,1}/S_iC_i$. In order to estimate the effect of covariates on the first year adoption level, the logistic model in (5) was used. Also, the logistic transformation of a growth rate was parametrized into the modified Bass model (4) to estimate the parameters of the covariates given in (6). Covariates were initially tested for possible correlations. All correlations were less than 0.6 and thus could be regarded as independent. Table 2 summarizes the factors that affect the first year adoption level and growth rate parameters in the modified Bass model.

**Table 2. Regression results**

| | **First year penetration ($A_{i,1}$)** $R^2$ = 0.92 | | **Diffusion rate ($B_i$)** $R^2$ =0.87 | |
|---|---|---|---|---|
| **Constructs** | **coeff** | **stand error** | **coeff** | **stand error** |
| *BBS* | 0.23*** | 0.03 | 0.14** | 60.059 |
| *HCI* | 0.03* | 0.016 | 0.08** | 0.035 |
| *INNOV* | 0.11** | 0.025 | 0.21*** | 0.051 |
| *GDP* | 0.01* | 0.007 | 0.02 | 0.025 |
| *ICTtrd* | 0.09*** | 0.029 | 0.08** | 0.029 |
| *RTB* | 0.012* | 0.006 | 0.02 | 0.015 |
| *IPR* | 0.12** | 0.038 | 0.02* | 0.011 |
| Significance level * = $p < 0.10$, ** = $p < 0.05$, *** = $p<0.01$ | | | | |

Results illustrate that all of the constructs have some impact on the diffusion process, verifying all of the hypotheses. However, there are important differences in the level of impact at the different stages of the diffusion.

First, there are two distinguished factors that exhibit the highest impact on the OSS diffusion. That is the telecommunication infrastructures (*BBS*) and innovation (*INNOV*). *BBS* exhibits the highest impact at the beginning of the diffusion process ($A_{i,1}$) with the highest coefficient (0.23, p<0.01) of all the covariates. This is quite expected as the initialization of OSS requires adequate technological infrastructure. *BBS* remains an important factor for the diffusion growth rate (*Bi*), with a coefficient of 0.14 at p<0.05. However, at this stage *INNOV* has the highest coefficient of the regression (0.21) at p<0.01. It can be deduced, that innovation activity of a country, is a critical factor for the growth of OSS technology. Again, innovation is also critical at the first stage of the diffusion, but with lower impact (0.11, p<0.05). This finding proves the close relationship of OSS and innovation.

The same applies for the quality of human capital, where it presents higher impact at the diffusion growth rate (0.08, p<0.05), than at the initialization stage (0.03, p<0.1). On the other hand, economic growth as expressed by GDP per capita, doesn't seem to have a high effect on the diffusion process, as it only exhibits a low impact at the first stage (0.01, p<0.1) and no impact at the rest of the diffusion. As a result, OSS evolves in social systems with higher education and innovation activity, than economic growth.

The finding comes in accordance with the *IPR* covariate, were it shows that governments with better regulation regarding *IPR* are expected to show higher OSS activity. Protection of *IPR*, would enhance innovation and ultimately OSS development. IPR has a positive impact on OSS growth on both stages, but its importance is higher at the first (0.12, $p<0.05$).

Second important factor is the ICT trade, which highly affects diffusion on both stages. However, its impact is more significant at the first stage of the development (0.09, $p<0.01$). This is an important finding, as it shows that exchange of ICT goods enhance exchange of knowledge and trigger the development of innovative technologies like OSS. Also, regulation that inhibits exchange would have a negative effect at the initialization of OSS, as shown by the regulation trade bars covariate (*RTB*). *RTB* has a positive impact (0.012, $p<0.1$) on countries with less restrictions on trade. However, *RTB* has no effect on the subsequent diffusion stages.

All of the critical factors under examination have an impact at the first stage of development, but the factors that determine OSS growth rate in descending order, are innovation and quality of human capital, telecommunications infrastructure, ICT trade and regulation protecting IPR. It can also be observed, that factors regarding a nation's infrastructure, economic status and institutions are more significant for the initial stage of OSS development. On the contrary, factors regarding a nation's human capital and innovation activity are more important elements for the OSS growth rate.

# 6. CONCLUSIONS

The research contributes to the OSS research by the creation of a model for the evaluation of the factors that impact OSS diffusion at two stages of growth: the initialization of the diffusion stage and the diffusion's growth rate. The model was developed under the prism of the theories of institutionalism, endogenous and exogenous growth. Results indicate that the proposed theoretical framework can be successfully deployed for the study of OSS across different countries.

Research findings show that the factors that determine OSS diffusion are innovation and quality of human capital, telecommunications infrastructure, ICT trade and regulation protecting IPR. This, in turn, shows that OSS evolves in social systems where knowledge, education and creativity is especially appreciated and developed. Economic growth and less regulation barriers in trade affect OSS only in the beginning of the diffusion process. Another important finding is the difference on the impact weight at the two diffusion stages. Again, factors related to the quality of human capital and innovation are critical for the growth phase of the diffusion.

Another interesting finding is the close relationship of OSS and innovation. OSS is an innovative technology, 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.

## 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. 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 datasets form reliable data sources, such as the World Bank and UN. In many cases, datasets have been operationalized by previous research and thus been validated by other researchers, as well. Finally, data have been statistically tested and validated. It should be noted that most of the research on cross-national level is based upon secondary data.

Studies of the critical factors for OSS diffusion across countries are quite limited and therefore this study can provide with some initial, yet helpful input that explain the OSS phenomenon. However, there are still a lot of research questions that call for a deeper understanding of the processes and events that underlie the diffusion process.

Moreover, findings of this study empirically validate the impact of innovation on OSS and open up new direction in the research of the relation between OSS and innovation.

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