

Internet penetration as national innovation capacity: worldwide evidence on the impact of ICTs on innovation development

Feng Xiong, Leizhen Zang & Yanyan Gao

To cite this article: Feng Xiong, Leizhen Zang & Yanyan Gao (2021): Internet penetration as national innovation capacity: worldwide evidence on the impact of ICTs on innovation development, Information Technology for Development, DOI: [10.1080/02681102.2021.1891853](https://doi.org/10.1080/02681102.2021.1891853)

To link to this article: <https://doi.org/10.1080/02681102.2021.1891853>



Published online: 05 Mar 2021.



Submit your article to this journal [↗](#)



Article views: 86



View related articles [↗](#)



View Crossmark data [↗](#)



Internet penetration as national innovation capacity: worldwide evidence on the impact of ICTs on innovation development

Feng Xiong^{a,b,#}, Leizhen Zang^{id c,d,#} and Yanyan Gao^{id e}

^aSchool of Economics and Management, Chongqing University of Posts and Telecommunications, Chongqing, People's Republic of China; ^bJinhe Center for Economic Research, Xi'an Jiaotong University, Xi'an, People's Republic of China; ^cThe College of Humanities and Development Studies, China Agricultural University, Beijing, People's Republic of China; ^dInstitute of State Governance, Peking University, Beijing, People's Republic of China; ^eSchool of Economics and Management, Southeast University, Nanjing, People's Republic of China

ABSTRACT

Information and communication technologies (ICTs) and innovations have profoundly reshaped global development. Although there are many works that have examined the direct effects of ICTs on national development in fields of economics, society and politics, the important role played by ICTs in national innovation capacity has been less widely explored from an empirical standpoint. This paper investigates the influence of Internet penetration on national innovation development, using cross-national panel data of 156 countries from 1995 to 2014. We find that Internet penetration has a significant but decreasing innovation-promotion effect, and this finding stood the test of various models and variable measures. Further study shows that there is a one-period lagged effect of Internet penetration on innovation, and political regimes moderate the innovation promotion effect of ICTs.

KEYWORDS

Internet penetration; innovation; panel data; machine learning; development

1. Introduction

The rapid adoption and diffusion of the Internet have attracted global scholars to examine the consequent socioeconomic impacts. The extant literature demonstrates that the Internet is able to facilitate economic growth (Hwang & Shin, 2017) and rural development (Gao et al., 2018), and raise labor productivity (Karamti, 2016), thus increasing the income of workers through the use of computers (Whitacre et al., 2014). In the twenty-first century, innovation development driven by ICTs has also gained increasing attention. Scholars have noted that ICTs can support the 'leapfrogging' growth in developing countries (Steinmueller, 2001). Qureshi (2015) pointed out that ICTs have created a better world by promoting innovation.

The Internet, as a major ICT (Menon, 2011), has enabled more and more innovations. Through the Internet, individuals can access the latest research and development (R&D) information and achieve international R&D cooperation, regardless of geographical distance (Sawhney et al., 2005). With the assistance of computers and the Internet, patent granting and application have also become more convenient, especially for international patent authorization and protection (Weiser, 2003).

Scholars found that numerous factors can determine innovation (Johne & Snelson, 1988; OECD, 2000), while it is still unclear how the Internet (or ICTs) affects innovation. Therefore, we try to bridge the gap in the existing literature by answering the following two questions: firstly,

CONTACT Leizhen ZANG ✉ zangleizhen@cau.edu.cn 📧 Rm206, The College of Humanities and Development Studies (COHD), China Agricultural University, Beijing 100193, People's Republic of China

[#]These authors contributed equally to this work.

Supplemental data for this article can be accessed <https://doi.org/10.1080/02681102.2021.1891853>

© 2021 Commonwealth Secretariat

whether Internet penetration promotes innovation development; secondly, whether the ICTs-innovation nexus is moderated by other institutional variables, such as democracy levels or political systems in different countries. By constructing panel data of 156 countries from 1995 to 2014, we come to the following conclusions. Firstly, using the fixed effects model and machine learning method, we find that Internet penetration immediately and significantly promotes innovation. At the same time, the diffusion of the Internet exhibits a one-period lagged effect on patent numbers. Secondly, there is an inverted-U shape relationship between Internet penetration and innovation. In addition, the effects of Internet penetration on innovation vary across countries with different political regimes or levels of democracy.

The rest of the paper is structured as follows. Section 2 reviews the existing literature about the impact of the Internet on patent counts. The methods and empirical models are specified in Section 3. Section 4 presents the empirical results, and Section 5 draws the conclusion.

2. Literature review and hypothesis development

2.1. ICTs and organizational innovation capacity

The broad meaning of the term ‘ICTs’ refers to the level of convergence of telephone networks, the Internet, artificial intelligence, big data, and social media applications (Zuppo, 2012). In both developing and developed countries, ICTs have already changed daily life at individual, organizational and national levels (Roztock & Weistroffer, 2016). Thus, the ICTs level of a country largely reflects its global competitiveness. For example, Qureshi (2013) found that ICTs can inspire new models for economic development, such as the emergence of eBay and Alibaba, two leading e-commerce sites.

ICTs are a powerful boost to organizational innovation capacity, i.e. the ability to enhance the competitiveness of an organization based on human resources and technology. For instance, the Internet can impact academic communities and business organizations in many ways (Applebee, 2002; Kumar & Manjunath, 2013). Firstly, it offers the possibility of saving a great deal of time and reducing the costs of searching for and transmitting scientific knowledge by changing the traditional mode of communication between R&D departments. More specifically, by taking full advantage of convenient tools such as e-mail, teleconferencing systems and virtual communities, researchers around the world can not only cooperate more efficiently with each other via the Internet, but also work more effectively by being aware of each other’s research progress (Kafourous, 2006). So in the era of ICTs, researchers can adopt cutting-edge information dissemination technology to conduct coordinated research, promoting academic performance and the efficiency of innovation activities (Fritsch & Franke, 2004). Secondly, the Internet has not only reduced the market transactions cost, but also accelerated the internal revolution of an R&D organization towards a flat organizational structure. Ollo-López and Aramendía-Muneta (2012) examined the impact of Internet on innovation and the competitiveness of the service sector, and found that the use of the Internet can contribute to more innovation and stronger competitiveness. Higón (2012) and Koellinger (2008) have also pointed out that the Internet can help improve the innovation performance of small and medium-sized enterprises (SMEs) through process reengineering. Moreover, Black and Lynch (2001) have also found that productivity is much higher in businesses in which there is a more common use of computers by non-managerial employees.

2.2. The effect of ICTs on innovation and development

ICTs promote innovation, which further promotes national development. Development is a concept with multiple dimensions, including economic growth, the sustainability of socio-cultural evolution, and the emergence of a higher life quality. It also involves both the short to medium-term outcome and the long-term societal transformation (Zheng et al., 2018). As highlighted by Anderson and Anderson (2012) in their research on the Gulf Cooperation Council (GCC) countries, ICTs can

significantly promote innovation capability, which is an important driving force for the development of a country.

A growing number of research provides evidence for the relationship between ICTs and development through case studies. Citizens in Romania are promoting economic development by supporting Internet banking and multichannel banking services, with the help of ICTs (Gurău, 2002). Likewise, the application of ICTs has direct effects on the social, human and economic dimensions of demand for development in Brazil (Malaquias & Hwang, 2017). In addition, research on Asia and Africa has shown that telephone penetration has a positive effect on economic growth in developing countries (Chavula, 2013; Levendis & Lee, 2013). Likewise, policy makers and entrepreneurs are also using the Internet to shape new ideas and practices (Hobday, 2005; Malerba & Mani, 2002).

However, there is still a gap in the extant literature on how ICTs promote the development of innovation, especially for empirical studies using worldwide panel data. Extant studies mostly use data from a single country or a single region, but the findings are contradictory. Pessimists may even question the ICTs' value in innovation and development. For example, some scholars noted that the Internet era has brought about problems like the overprotection of intellectual property and has even hindered innovation (Caso & Guarda, 2019). However, optimists stress that the Internet presents opportunities for latecomers to promote innovation at low costs (Sell, 2013). But in what ways does the Internet influence national innovation in a global perspective? Scholars, including Qureshi (2015), called for empirical contributions.

2.3. Hypothesis development

To examine the impacts of the Internet on innovation, we developed three hypotheses. Previous literatures have tentatively explored the relationship between ICTs and national innovation capacity from a macroscopic view. Soto-Acosta et al. (2014), using structural equation modeling on a dataset of 535 Spanish small and medium-sized enterprises, found that IT skills affects the Web Knowledge Sharing and organization innovation. However, the impact might have lagged effects since it takes time for ICTs to be adopted for innovation purposes. Holt and Jamison (2009) have also found that there is a time lag before enterprises actually start to use a relatively new information technology. Given these rationales, we propose the first hypothesis:

H1: *Ceteris paribus*, ICTs can promote national innovation, and there may be a lagged effect.

The law of diminishing marginal utility has been broadly observed in economic theories and social realities (Mcauliffe, 2015). Firstly, Internet penetration has a ceiling value (100%), and shows an S-shaped diffusion pattern across countries (Andrés et al., 2010), which may produce a statistically decreasing effect on national innovation. Secondly, the existence of digital divide makes it difficult for some citizens to access and make full use of the Internet (Warschauer, 2004). At this time, the public can neither enjoy the convenience brought by the Internet, nor use the Internet to realize their innovative idea. Thirdly, since the renowned economist Simon Kuznets first suggested that there is an inverted U-shape relationship between economic growth and income inequality, researchers have extensively explored whether inverted U-shape relationships exist in social and economic development (Acemoglu & Robinson, 2002). Following this logic, there may be such a relationship between Internet penetration and innovation, or a threshold effect in this relationship (meaning that Internet penetration has a reduced effect on innovation if it is larger than a certain value, i.e. the threshold). The authors thus propose the second hypothesis:

H2: *Ceteris paribus*, due to the existence of a ceiling value for Internet penetration, ICTs have a decreasing effect on national innovation.

Extant studies noted that economic development is always closely related to the property rights system of a country (North & Thomas, 1976). Based on this finding, some studies pointed out that the impact of the Internet on innovation varies in different political contexts (Zhu et al., 2006).

This result was based on two factors. Firstly, the Internet is highly sensitive to institutions. Research in politics has shown that the efficiency of the Internet is strongly related to democracy level (Best & Wade, 2009; Chung, 2008). In non-democratic countries, the Internet may become a tool for repression instead of innovation (Rød & Weidmann, 2015). Secondly, presidential system and parliamentary system are two main forms of contemporary democratic and republican government. In a presidential system, the head of government or the President is elected without being accountable to parliament, whereas in a parliamentary system, heads of state and government are different. The executive's power relies on the parliament's support. Election campaign is more common in presidential countries, and the influence of Internet on countries with presidential system is more profound (Benoit & Hansen, 2004; Dalrymple & Scheufele, 2007). Having examined the different influences of the Internet on innovation in presidential and parliamentary countries and countries with different levels of democratization, the authors propose the third hypothesis.

H3: The innovation promotion effect of ICTs is heterogeneous based on different democracy levels and political systems.

3. Research strategy

3.1. Variables and data

R&D (Research and development) investment, a number of papers in top journals and national patent data are often used to represent a country's innovation capacity. But in an era of capital-fuelled entrepreneurship, investment from governments and companies does not always go to innovation. More and more scholars are using patent data as a proxy variable for national innovation (Abraham & Moitra, 2001; Sawhney et al., 2005). The authors also regard patent counts as a measurement of a country's innovation capacity. More specifically, this study uses US NBER patent data, which contains detailed information on patents granted by the US Patent and Trademark Office (USPTO) from 1995 to 2014, to construct proxies for innovations. We prefer USPTO data to that of the World Intellectual Property Office (WIPO), because the latter has a large proportion of data missing, and patents granted by different countries sometimes represent very different levels of innovation. Patents granted in one country may not be innovative enough in another, and may therefore not be acknowledged by foreign patent offices. Since the US is the largest consumer market of technologies in the world, it has generally been accepted in prior studies that all important innovations have been patented by the US patent office (Gao et al., 2017). Thus, this paper uses the number of patents filed by the USPTO as a measurement of innovation for countries around the world. According to the research goal of this paper and the literature review above, the number of granted patents is a dependent variable.

Obviously, ICTs is the core independent variable studied in this paper, but how should researchers measure the level of development of ICTs? Since its launch by the United Nations International Telecommunication Union in 2013, the ICTs Development Index (IDI) has gained much attention worldwide. However, research has often used the numbers of Internet hosts, Internet users, personal computers and mobile phones as indicators of ICTs (Balioune-Lutz, 2003), since IDI data are limited due to its short history. In view of the fact that Internet penetration is an important component of IDI, and data for this variable are relatively more complete, the authors chose Internet penetration as the independent variable. The Internet is a key driver of the most recent industrial revolution and has continually accelerated the pace of innovation. With the highest probability of generating patented innovations, it has also been involved in a large number of patent applications and plays a crucial role in economic development and academic research. The authors adopted the Internet coverage rate (Internet users per 100 people) as the main measurement for Internet penetration. It has been frequently used in prior cross-national studies about the relationship between Internet application and economic growth (C. Choi & Yi, 2009). To provide a comprehensive picture of Internet penetration across the world, the paper used the number of fixed-broadband

subscriptions per 100 people and the number of secure Internet servers per million people as alternative measurements. The data for these measurements were obtained from the World Bank Open Data (WBOD).

In order to make the empirical model more robust and enhance the explanatory power of the model, the authors introduced several control variables. Undoubtedly, as data have become increasingly abundant, a variety of control variables have been chosen by scholars and were adopted in the literature reviewed above. However, the logic of control variable selection in extant studies was mostly based on the availability of data or the preferences of the researchers, inevitably leading to variable selection bias and directly affecting the overall validity of the model. To overcome these deficiencies, we adopted a machine learning method in an innovative way to control variable selection. The random forest technique put forward in 2001 is an effective feature selection method (Cutler & Zhao, 2001). It is also a valuable machine learning method for classification, regression, survival analysis, feature selection and other tasks. It operates by constructing numerous decision trees while training and producing a class that represents the mode of the classifications or mean prediction (regression) of the individual trees (Genuer et al., 2010). Using values of the Gini and permutation importance, the random forest method can effectively predict the importance of different variables when analysing an unbalanced set of panel data.

The control variables applied in this study are drawn from the Quality of Government (QOG) dataset (Teorell et al., 2015). In this paper, a random forest approach is firstly used to exclude variables that are unrelated to the national innovation capacity from more than 100 variables in the QOG dataset. After the initial screening, 26 related variables are selected (see Table A1 in the Appendix). Therefore, the authors referred to the values of Gini importance and missing data when selecting variables, and created a sequence of variables based on their Gini importance values, using a random forest model containing all control and dependent variables. This helps to enhance the explanatory power of the model, meaning that the estimation of the technological innovations' effect on governance efficiencies is relatively accurate. Then, collinearity analyses are carried out in order to eliminate those variables that are highly related to each other. Finally, based on the results of the random forest method and extant studies, a group of control variables that are valuable for this research were selected. In order to reduce bias resulted from the omission of variables, the variable of labor freedom, which has a large amount of data missing, was eliminated.

Based on the analysis above, the main control variables for the demographic, economic and political spheres were chosen. Previous studies carried out at both micro and macro levels have found that innovation is influenced by economic factors such as the real GDP, urbanization rate (Archibugi et al., 2013), population density (Abel et al., 2012), social freedom (Lehmann & Seitz, 2016) and political regimes. Therefore, the authors controlled these potential determinants of innovation. In addition, the average number of years of tertiary schooling is used to measure the stock of human capital for each country. These data were collected from the study of Barro and Lee (2013), who estimated the average number of years of education for both female and male adults at different levels every five years. We filled the gaps in these data with the closest observations. For example, if the estimated average is five years of tertiary schooling for a particular country in the year 2000, then it is assumed that the observations for the following four years for the same country is five. The authors also controlled the variable of population density in order to include its effects on knowledge spill-over within a country, since population density contribute to innovations by facilitating social interactions and knowledge spill-over. These data are also drawn from the WBOD. Economic openness is also controlled and measured using the share of imports and exports in GDP. The index of economic freedom ranges from 0 (minimum) to 100 (maximum). Finally, the authors controlled the variables of institutional determinants of national innovation, including political regimes, cultural diversities, political imprisonments and political stability. The paper uses the level of democracy (Freedom House/Imputed Polity) proposed by the Polity IV Project (Marshall et al., 2015), which used values from 0 (full autocracy) to 10 (full democracy) to measure the differences among political regimes across the world. The tax burden and government efficiency are also included in the model.

The authors compiled and combined all variables and countries in the aforementioned datasets, and obtained panel data for 214 countries or regions. However, to ensure data quality, research samples were omitted if large portions of the data (15% or more for any category or year) missed. Overall, 156 countries or regions were used as research samples in this paper. In addition, when determining the period of time to be studied, we took into consideration the development history of the Internet, and the impacts of the 1989 revolutions and the disintegration of the Soviet Union, which caused many countries to change their names. In the end, all the analyses in the paper are based on unbalanced panel data for 156 countries or regions from 1995 to 2014, with 2014 being the latest available year.

3.2. Empirical methods

To further validate the hypotheses and explore the influence mechanism between Internet penetration and innovation capacity, various regression models can be established and the results can be compared in order to test the robustness of the research. The authors firstly employed the following fixed-effects model:

$$\ln(1 + \text{patent}_{it}) = \ln(1 + \text{patent}_{i,t-1}) + \alpha + \text{net}_{it}\beta + \text{Controls}_{it}\delta + c_i + p_t + \varepsilon_{it} \quad (1)$$

where *patent* denotes patent counts and *net* represents Internet penetration. A value of 1 is added to *patent* so that logarithms are non-negative. The term *controls* refers to the vector of control variables previously discussed. $i = 1, 2, \dots, N$ denotes the country, and $t = 1995, \dots, 2014$ represents the year. c_i and p_t indicate the country fixed effects and year effects respectively. ε_{it} represents the disturbance, and β and δ are coefficients to be estimated.

We used the least squares dummy variables (LSDVs) estimation method to regress the main model. The fixed effect model is commonly used in panel regression models, in which the residual receives a restriction $\sum(\varepsilon_{it}|\alpha_i, x_{it}) = 0, i = 1, 2, \dots, N$, comparing the random effect model with $\sum(\varepsilon_{it}) = 0, i = 1, 2, \dots, N$. It is clear that the one-year lag in patent counts includes some information that was not considered in the model, and this is referred to as the endogenous problem of omission of the explaining variables. Equation (1) with the lagged patent counts can reduce the endogenous problem and increase the power of its explanations. The LSDVs estimation is a well-known and popular method for estimating the coefficients of a fixed effect model, as in Equation (1). When considering only the year fixed effect and the heteroscedasticity, the feasible generalized least squares (FGLS) estimation method is the best choice. Compared to the ordinary least squares approach, FGLS allows the solution to be more consistent and stable, eliminating heteroscedasticity by adding a weight to explanatory variables. For both year and country fixed effects, the maximum likelihood estimation (MLE) is an appropriate way of obtaining the regression results.

4. Empirical results and Discussion

4.1. Description of data

Descriptive statistics for all variables are presented in Table 1. It can be seen that the number of observations (or data points) is very different among variables. In addition, the means of different variables calculated in this study are generally consistent with those from the World Bank, suggesting that the countries selected are highly representative.

Figure 1 shows the relationship between Internet penetration and the log of patent counts, in which a polynomial-simulating curve is derived based on the two-way scatter. It shows that Internet penetration is positively associated with patent counts, and patent counts increase as Internet penetration grows. In other words, there is a convex linear positive correlation between Internet penetration and national innovation capacity both in the periods of 1995–2005 and 2006–2015.

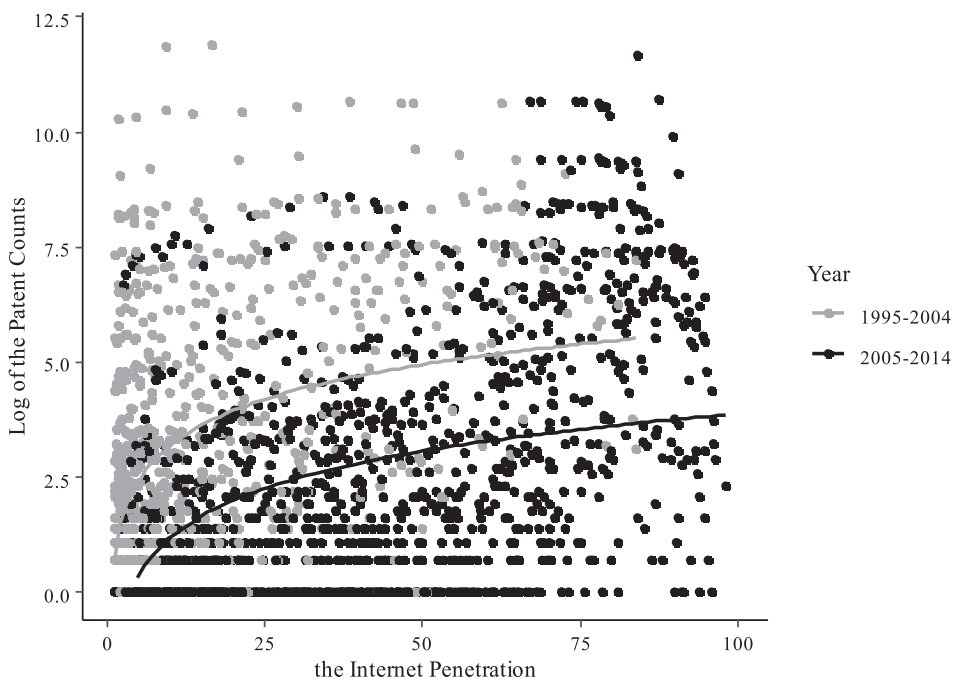
Table 1. Descriptive statistics for all variables.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Log of patent counts	2,987	2.120	2.673	0	12.266
Internet users (per 100 people)	2,987	22.940	26.607	0	98.16
Average years of tertiary schooling	2,372	0.390	0.310	0.003	1.587
Log of population density (people per square km of land area)	2,977	4.201	1.429	0.392	9.842
Level of democracy (Freedom House/Imputed Polity)	2,987	6.748	3.138	0	10
Economic freedom index	2,662	60.248	11.430	1	89.405
Political stability	2,411	-0.027	0.972	-3.185	1.668
Government efficiency	2,394	0.105	0.982	-2.258	2.430
Political corruption	2,338	1.260	0.826	0	2
Log of GDP per capita, PPP (constant 2005 international \$)	2,881	8.633	1.454	5.209	11.886
Telephone lines (per 100 people)	2,891	21.613	19.716	0	132.953
Cultural diversity	2,555	0.299	0.204	0	0.733
Tax burden	2,056	72.471	15.036	10	99.9
Financial freedom	2,057	53.685	18.621	10	90
Economic openness	2,819	86.854	47.425	0.309	439.657
Political system	2,489	0.383	0.486	0	1
Fixed broadband subscriptions	1,896	8.149	10.797	0	46.761
Scientific and technical journal articles	2,373	5.593	2.885	0	12.895

Note: Internet users (per 100 people) represents the Internet penetration, it also indicates the ICTs of a country.

4.2. Multi-Collinearity test

In order to overcome the strong correlation between the explanatory variables and ensure that the correlation coefficient estimated in the model is free of distortion or inaccuracy, we performed a multi-collinearity test and used variance inflation factor (VIF) proposed by Marquardt (1970). Practical experience indicates that if any of the VIFs exceeds 10, it is an indication that the associated regression coefficients are poorly estimated because of multi-collinearity (Montgomery et al.,

**Figure 1.** The relationship between Internet penetration and log of patent counts.

Data sources: the log of patent counts is from the USPTO, and Internet penetration is represented by the number of Internet users per 100 people, from World Bank Open Data.

Table 2. Multi-collinearity analysis of variables.

Variable	VIF	SQRT VIF	Tolerance	R-Squared
Internet penetration	2.67	1.63	0.3749	0.6251
Average years of tertiary schooling	1.93	1.39	0.5172	0.4828
Log of population density	1.53	1.23	0.6557	0.3443
Level of democracy	2.73	1.65	0.3661	0.6339
Economic freedom index	5.96	2.44	0.1677	0.8323
Political stability	3.11	1.76	0.3211	0.6789
Government efficiency	9.90	3.15	0.1010	0.8990
Political corruption	2.27	1.51	0.4398	0.5602
Log of GDP per capita	6.49	2.55	0.1541	0.8459
Telephone lines	7.20	2.68	0.1388	0.8612
Cultural diversity	1.23	1.11	0.8101	0.1899
Tax burden	2.13	1.46	0.4684	0.5316
Financial freedom	2.87	1.70	0.3480	0.6520
Economic openness	1.57	1.25	0.6377	0.3623
Mean VIF	3.69			

1982). Table 2 indicates that the VIF for all the variables are less than 10, suggesting that multi-collinearity does not exist among the variables (García et al., 2015). Therefore, all of these variables can be used in the following analysis of the multiple linear regression model.

In addition to multicollinearity, researchers often have to deal with false regression in empirical analysis. I. Choi (2001) developed unit root tests for panel data and indicated that Fisher-type tests were a key approach from a meta-analysis perspective, since it does not require strongly balanced data. This approach combines p -values using the inverse chi-squared, inverse-normal and inverse-logit transformations. The null hypothesis of this test is that all panels contain a unit root, and the log of patent counts is stationary. Based on the log of patent counts, the Fisher-type test gave the results shown in Table A4 in the Appendix. The test results show that the null hypothesis is significantly rejected. Hence, the results of panel statistical regression model are effective, and there is no possibility of false regression.

4.3. Baseline results

The baseline results for the effect of Internet penetration on innovation are shown in Table 3. The first model shows the results estimated using the random effect method, which can be used as a comparison with the results of the fixed effect model. The results of the Hausman test proved that all of the fixed effect models are superior to the random effect model. Models 2–4 are the results estimated from the fixed effect model based on Equation (1).

In Model 2, there is no lag term for the dependent variables, and the explanatory power of Model 2 is therefore significantly weaker than that of Model 3, based on the results of the adjusted R-squared and Hausman tests. The presence of first-order lag for dependent variables can solve the problems caused by missing variables, thus improving the accuracy of the model. In addition, a time trend has been added to Model 4 on the basis of Model 3, which shows that the Internet has a positive impact on innovations. Model 5 is the result of FGLS regression, which considered the heteroscedasticity and only the time trend without country effects. This result also shows that Internet penetration has a significantly positive impact on national innovation capacity. Thus, the immediate effects proposed in Hypothesis 1 are verified by the fixed effects models; in other words, the increase in Internet penetration immediately and significantly promotes the innovation level of a country.

In addition, Model 5 takes the factor of different regions into account to demonstrate the different levels of innovation among different regions. It can be seen clearly that the innovation level in East Asian and Pacific region is significantly higher than that in other regions. The lowest innovation level goes to the Middle East and North Africa. The result is highly consistent with the widely

Table 3. Baseline results.

Variable	Model 1 RE	Model 2 FE	Model 3 FE	Model 4 FE	Model 5 FGLS
One-year lag of log of patent counts	0.9695*** (126.47)		0.4393*** (17.08)	0.4332*** (16.72)	
Internet penetration	−0.0009 (−1.22)	0.0075*** (6.23)	0.0037*** (3.32)	0.0034* (2.50)	0.0181*** (10.78)
Square of average years of tertiary schooling attained	0.0436 (1.09)	−0.3051* (−2.26)	−0.2648* (−2.17)	−0.2566* (−2.05)	1.3701*** (16.00)
Log of population density	0.0107 (1.15)	0.7141*** (4.58)	0.5093*** (3.51)	0.4772** (2.59)	0.1058*** (6.72)
Level of democracy	−0.0017 (−0.28)	0.0090 (0.49)	0.0082 (0.49)	0.0041 (0.24)	0.0457*** (3.86)
Economic freedom index	−0.0014 (−0.72)	0.0137*** (3.52)	0.0094** (2.64)	0.0077* (2.15)	−0.0375*** (−12.17)
Political stability	−0.0324 (−1.34)	−0.2092*** (−4.29)	−0.1285** (−2.87)	−0.1286** (−2.85)	−0.5895*** (−14.87)
Government efficiency	0.0530 (1.42)	0.3018*** (3.75)	0.1531* (2.06)	0.1580* (2.02)	1.0015*** (15.05)
Political imprisonment	−0.0078 (−0.36)	0.0829** (3.03)	0.0630* (2.53)	0.0657** (2.61)	−0.1644*** (−4.42)
Log of GDP per capita	0.0302 (1.52)	0.5544*** (5.00)	0.3122** (3.05)	0.3308* (2.50)	0.3451*** (8.88)
Telephone lines	0.0012 (0.77)	0.0128*** (3.54)	0.0078* (2.35)	0.0052 (1.51)	0.0584*** (19.55)
Cultural diversity					−0.5724*** (−4.66)
Europe & Central Asia					−1.0672*** (−12.21)
Latin America & Caribbean					−0.7806*** (−8.81)
Middle East & North Africa					−1.4517*** (−15.18)
South Asia					−0.8174*** (−3.81)
Sub-Saharan Africa					−0.2373** (−2.64)
Constant	−0.1154 (−0.60)	−6.5789*** (−6.03)	−4.2599*** (−4.16)	−4.2185** (−2.75)	0.3599 (0.96)
Observation	1389	1410	1389	1389	1342
# of countries	156	156	156	156	156
Country fixed effects	Yes	Yes	Yes	Yes	No
Year fixed effects	No	No	No	Yes	Yes
Adjusted <i>R</i> -squared		0.170	0.323	0.327	
Hausman test based on Model 1		2100.85***	361.08***	143.99***	

Note: The *T*-tests values of parameter estimation are in parentheses; *, ** and *** denote significance levels of 5%, 1% and 0.1%, respectively (the same in following parts); East Asia & Pacific region is the reference for comparison with other regions, including Europe & Central Asia, Latin America & Caribbean, Middle East & North Africa, South Asia, Sub-Saharan Africa.

acknowledged facts that the Asia-Pacific region is most active in economic and technological development, while the Middle East and North Africa have long been affected by war, and their levels of innovation were significantly lower.

The results above show that Internet penetration has a significantly positive impact on innovation. And this positive impact is immediate. Based on the analysis of Model 2 in Table 4, we can draw the conclusion that after a period of time, improved Internet penetration still exerts a significantly positive effect on patent counts, meaning that Internet penetration has a lagged effect. Thus, the lagged effects in hypothesis 1 are further confirmed.

In the meantime, Models 3 and 4 demonstrate that Internet penetration has an inverted U-shaped effect on the number of innovations. In other words, with an increase in Internet penetration, its spillover effects on innovation will gradually diminish, and hypothesis 2 is therefore supported.

The square of the average years of tertiary schooling exerts a significantly negative effect on innovations, meaning that effect of education on innovation is reverse U-shaped. Therefore, the positive

Table 4. Results from fixed effect models with a lagged variable.

Variable	Model 1 RE	Model 2 FE	Model 3 FE	Model 4 FE
One-year lag of log of patent counts	0.4393*** (17.08)	0.4401*** (17.11)	0.4353*** (16.97)	0.4303*** (16.65)
Internet penetration	0.0037*** (3.32)		0.0112*** (4.45)	0.0109*** (3.91)
One-year lag of Internet penetration		0.0036** (3.21)		
The square term of Internet penetration			−0.0001*** (−3.32)	−0.0001** (−3.08)
Square of average years of tertiary schooling attained	−0.2648* (−2.17)	−0.2701* (−2.19)	−0.1972 (−1.60)	−0.1837 (−1.45)
Log of population density	0.5093*** (3.51)	0.5374*** (3.76)	0.4207** (2.86)	0.4394* (2.38)
Level of democracy	0.0082 (0.49)	0.0080 (0.47)	0.0061 (0.37)	0.0037 (0.22)
Economic freedom index	0.0094** (2.64)	0.0094** (2.62)	0.0109** (3.05)	0.0092* (2.53)
Political stability	−0.1285** (−2.87)	−0.1281** (−2.86)	−0.1311** (−2.94)	−0.1338** (−2.97)
Government efficiency	0.1531* (2.06)	0.1578* (2.12)	0.1610* (2.17)	0.1574* (2.02)
Political imprisonment	0.0630* (2.53)	0.0628* (2.52)	0.0614* (2.47)	0.0642* (2.55)
Log of GDP per capita	0.3122** (3.05)	0.3233** (3.18)	0.2154* (2.03)	0.2660* (1.99)
Telephone lines	0.0078* (2.35)	0.0085* (2.51)	0.0021 (0.57)	0.0003 (0.08)
Constant	−4.2599*** (−4.16)	−4.4755*** (−4.49)	−3.0564** (−2.83)	−3.5032* (−2.26)
Observation	1389	1389	1389	1389
# of countries	156	156	156	156
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	No	No	No	Yes
Adjusted <i>R</i> -squared	0.323	0.323	0.328	0.332

effect of education gradually diminishes as the average years of tertiary schooling increase. Government efficiency and the log of GDP per capita have a significantly positive effect on innovation. Overall, the conclusions presented above are consistent with current research results.

4.4. The Moderating effect of democracy and political systems

From the analysis above, we can see that Internet penetration has a significantly positive effect on national innovation. In order to know whether there are significant differences in these effects among countries with different democracy levels or political systems, we classified these effects according to the level of democracy. Figure 2 illustrates the distribution of the average values of the degree of democracy in different countries. The mean was chosen as the threshold (6.6864). Countries that are above the threshold should be regarded as advanced democracies (95), while countries below the mean are less advanced democracies (61), as shown in Table A3 in the Appendix.

The political system is a very important factor reflecting the social development of a country. Therefore, we examined whether different political systems will affect the influence of Internet penetration on innovation. The political systems of the 156 sample countries in this study are classified into two types: presidential and parliamentary system.

Table 5 presents the regression results for the fixed effect model for different democracy levels and political systems. Advanced democracy in Model 1 indicates that the influence of Internet penetration on innovation is positive but non-statistical significant. However, Less advanced democracy in Model 2 shows that the regression coefficient of Internet penetration on innovation increased from 0.0016–0.0088, and it is statistically significant. The results in Table 5 show that the coefficients

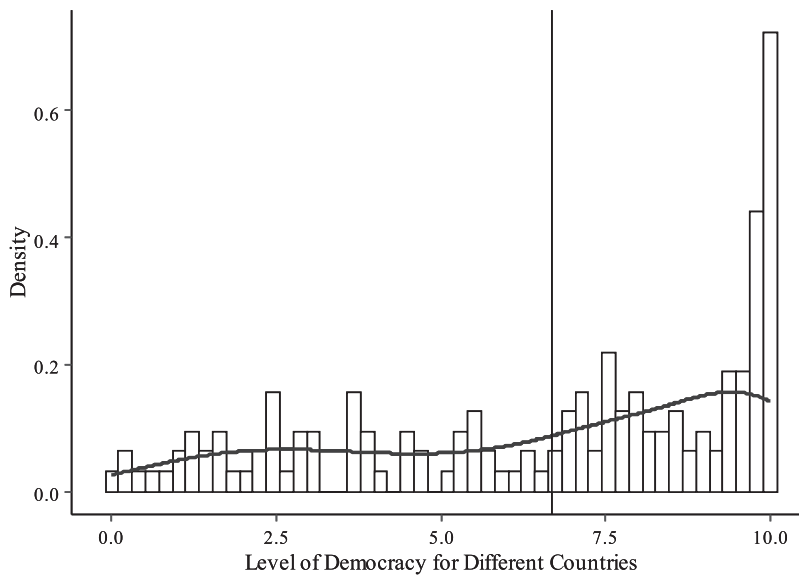


Figure 2. Average level of democracy for different countries.

of both the interactions among Internet users and the level of democracy are positive and significant, proving that the impact of Internet penetration on innovation varies significantly for different levels of democracy, and that Internet penetration has greater effects on innovation in less advanced democracies.

The regression results from Models 4 and 5 show that in parliamentary countries, the impacts of Internet penetration on innovation are trivial; while in presidential countries, the effects are more

Table 5. Comparison analysis for different levels of democracy and political systems.

	Model 1 Advanced democracy (>6.6864)	Model 2 Less advanced democracy (≤ 6.6864)	Model 3 All data	Model 4 Parliamentary countries	Model 5 Presidential countries	Model 6 All data
Sample						
One-year lag of log of patent counts	0.3357*** (10.43)	0.5237*** (12.14)	0.4300*** (16.74)	0.4525*** (11.76)	0.3954*** (11.60)	0.4350*** (16.91)
Internet penetration	0.0016 (1.29)	0.0088** (2.75)	0.0030** (2.68)	−0.0001 (−0.09)	0.0102*** (4.82)	0.0025* (2.07)
Interaction of internet users and less advanced democracy (=1)			0.0083*** (3.87)			
Interaction of internet users and presidential countries(=1)						0.0048** (2.87)
Basic control variables	yes	yes	yes	yes	yes	yes
Constant	−4.4034** (−3.08)	−2.4597 (−1.50)	−3.1311** (−2.96)	−8.4336*** (−4.18)	−1.6800 (−1.28)	−3.4543** (−3.24)
Observations	916	473	1389	548	836	1384
# of countries	95	61	156	55	91	156
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	No	No	No	No	No	No
Adjusted R-squared	0.273	0.425	0.331	0.415	0.277	0.327

Note: Less advanced democracy and presidential countries are all dummy variables, and the value 1 represents the samples of less advanced democracy or presidential countries respectively. Other samples are defined as zero.

evident. Specifically, if Internet penetration in a presidential country increases by 1%, its national capacity for innovation will increase by 1.02%. In addition, Model 6 shows that the coefficient of both interaction among internet users and political systems is positive and significant; this supports the conclusion that there are significant differences in the impacts of Internet penetration on innovations under different political systems. In addition, the results of the Adjusted R-squared in Table 5 show that the model has strong explanatory power, indicating that the analysis above is reliable. Hypothesis 3 is therefore validated.

4.5. Sensitivity analysis

4.5.1. Results with more control variables

To test the robustness of our previous results, we first added other control variables based on the original model to test the stability of explanatory variables. A comparison was drawn between the 'basic model' and the 'test model' in Table 6, from which it can be seen that if the control variables are increased, the regression coefficients of other control variables change slightly, and the directions of these changes are mostly consistent. Moreover, the control variables added by the test model have a high proportion of missing data, which affects the explanatory power of the model. The conclusion of this study for the fixed effect model is therefore relatively stable.

4.5.2. Results for the alternative measure of innovation and Internet penetration

The authors further conducted sensitivity analysis using alternative measures of national innovation and Internet penetration presented in Table 7. Using the number of scientific and technical journal articles as measurements for national innovation capacity, the results are shown in Model 1–3, and are similar to those in Tables 3 and 4. Using the fixed effects model, it shows again that the immediate effects of Internet coverage rates are statistically significant (see Model 1). Meanwhile, a significant lagged effect of Internet penetration on scientific and technical journal articles is shown in the full model reported in column 2. Moreover, the fixed effect model shows a significant reverse U-shaped relation between Internet penetration and the number of journal articles (see Model 3). Thus, the results from alternative dependent variables also prove a positive effect of Internet penetration on national innovation.

Model 4–6 in Table 7 present the results where the log of fixed broadband subscriptions was used to measure Internet penetration. The results are similar to those in the previous tables. Using the fixed effects model, we find that fixed broadband subscriptions are significantly associated with patent counts, and the one-year-later lagged effect was also statistically significant.

Table 6. Robust test results.

Variable	Basic model	Test model
One-year lag of log of patent counts	0.4393*** (17.08)	0.3627*** (12.32)
Internet penetration	0.0037*** (3.32)	0.0052*** (4.06)
Basic control variables	yes	yes
Other control variables	No	yes
Constant	−4.2599*** (−4.16)	−2.4539* (−2.15)
Observations	1389	1141
# of countries	156	156
Country fixed effects	Yes	Yes
Year fixed effects	No	No
Adjusted R-squared	0.323	0.241

Note: The basic control variables are the same as in the Table 5. Other control variables are Tax burden, Financial freedom, Economic openness.

Table 7. Robustness check using an alternative measurement.

	Model 1 The log of scientific and technical journal articles	Model 2 The log of patent counts	Model 3	Model 4	Model 5
Internet penetration	0.0101*** (11.16)		0.0184*** (8.86)		
The one year lag of Internet penetration		0.0100*** (10.97)			
The quadratic term of Internet penetration			−0.0001*** (−4.43)		
The log of fixed broadband subscriptions				0.0218 (1.72)	
One-year lag of log of fixed broadband subscriptions					0.0303* (2.35)
Basic control variables	yes	yes	yes	yes	yes
Constant	−17.4895*** (−20.93)	−17.8658*** (−21.59)	−16.1028*** (−18.17)	−9.6343*** (−5.05)	−9.1859*** (−4.41)
Observations	1295	1275	1295	1034	954
# of countries	119	119	119	116	115
R-Square	0.722	0.719	0.727	0.169	0.175

Note: The basic control variables are the same as in the Table 5.

5. Conclusion and implications

As shown in many of the studies mentioned above, ICTs have impacted on national development in fields of economics, society and politics in both developing and developed countries. National innovation is the fundamental motivation of development in the information age. The question caught people's attention whether ICTs have significant influence on national innovation. If so, ICTs will indirectly promote the development of a country through advancing national innovations. This paper, with data from USPTO, answers the question with empirical results, showing that Internet penetration contributes significantly to national innovations. Furthermore, we find a decreasing and lagged effect of Internet penetration on national innovation. More specifically, the Internet has greater influence on innovation at the beginning of its penetration; then, due to the ceiling effect, this influence decreases as penetration increases. It should be noted that the models used for analysis in this paper show that the regression coefficient of independent variables is stable and significant. Thus, the changes in the coefficients of some control variables in different models do not influence the final explanatory power.

This study provides new insights and enhances our understanding of the relation between ICTs and national innovation development. Firstly, our results imply that ICTs provide new opportunities for less developed countries or less advanced democracies, characterized by a lower level of R&D, education, urbanization rate and poorer governance, to catch up with developed countries and advanced democracies through innovation. In other words, the influence of the Internet on innovation, is less dependent on socioeconomic variables, which means it can overcome socioeconomic constraints on innovation. Secondly, our results also provide new evidence for the importance of institutional factors in stimulating innovation through knowledge spill-over. In presidential regimes, Internet penetration can better promote innovation. Despite high government turnover in many presidential regimes, the positive influence on innovation is not weakened; in other words, the influence mechanism will be more effective under a weak or unstable government. Thirdly, the inverted U-shaped relation between Internet penetration and innovation shows that the increase in innovation popularity and innovation levels cannot only depend on ICTs; the effects of other determining factors, including the political institution of a country, should also be

considered. Our findings provide further empirical support for the study of ICTs for development (Qureshi, 2015). This paper uses an innovative machine learning approach to implement variable selection. It greatly improved the research efficiency, and solved the complex problem of variable selection researchers face when analysing panel data in the age of Big Data.

Our results also have several potential policy implications. The results indicate that developing countries can make better use of ICTs to exploit their late-mover advantages to the full extent in terms of national innovation development. It means that striving for a predominant position in ICTs should be the principal strategy that late-mover countries should adopt. Meanwhile, for countries at different democratic levels, numerous social and institutional interactions should be made as the primary ways for nurturing and accumulating social capital. Better social collaboration and interaction networks will help the Internet generate greater knowledge spill-over effects. Nonetheless, more evidence is needed to fully understand ICTs' impact on fundamental economic variables, such as labor, total factor productivity and patterns of trade. In addition, a spatial econometric model could be introduced in future studies to analyse the influence of ICTs on national innovation development.

Acknowledgements

The authors wish to thank reviewers and editors, for giving their time and expertise to review the early manuscript and help refine our idea. An earlier and shorter version of this article was presented orally as part of a symposium at the 8th (2019) Chinese Forum on Public Administration in Tianjin, China. The authors are solely responsible for any remaining errors.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by The National Social Science Fund of China [grant number: 20AZZ002]; National Office for Philosophy and Social Sciences.

Note on contributors

Dr. Feng Xiong is a researcher in the School of Economics and Management of Chongqing University of Posts and Telecommunications, and mainly engaged in empirical research in the political, economic and social fields based on data process, data visualization and data analysis. His papers are published in *Social Science Computer Review*, *International Journal of Education Development* and other journals.

Dr. Leizhen Zang is a professor at the College of Humanities and Development Studies (COHD), China Agricultural University, Beijing. He is also a senior fellow at the Institute of State Governance at Peking University and Soochow University. His research covers comparative politics and public policy. His articles have been published in numerous international, peer-reviewed journals, including *Research Policy*, *Social Science Computer Review*, among many others. Dr. Zang is also a lead researcher for the National Social Science Foundation of China.

Dr. Yanyan Gao is an associate professor at the School of Economics and Management, Southeast University, China. His research mainly involves public policy evaluations and the impacts of infrastructure endeavors like high-speed rail and natural gas pipeline projects. Dr. Gao has published widely in international, peer-reviewed journals, including *Research Policy*, *World Development*, as well as in leading Chinese journals, such as the *Economic Research Journal* and the *China Rural Survey*.

ORCID

Leizhen Zang  <http://orcid.org/0000-0003-3521-8301>
Yanyan Gao  <http://orcid.org/0000-0003-0326-504X>

References

- Abel, J. R., Dey, I., & Gabe, T. M. (2012). Productivity and the density of human capital. *Journal of Regional Science*, 52(4), 562–586. <https://doi.org/10.1111/j.1467-9787.2011.00742.x>
- Abraham, B. P., & Moitra, S. D. (2001). Innovation assessment through patent analysis. *Technovation*, 21(4), 245–252. [https://doi.org/10.1016/S0166-4972\(00\)00040-7](https://doi.org/10.1016/S0166-4972(00)00040-7)
- Acemoglu, D., & Robinson, J. A. (2002). The political economy of the kuznets curve. *Review of Development Economics*, 6(2), 183–203. <https://doi.org/10.1111/1467-9361.00149>
- Anderson, E., & Anderson, E. (2012). ICT-integrated education and national innovation systems in the gulf cooperation council (GCC) countries. *Computers & Education*, 59(2), 607–618. <https://doi.org/10.1016/j.compedu.2012.02.006>
- Andrés, L., Cuberes, D., Diouf, M., & Serebrisky, T. (2010). The diffusion of the Internet: A cross-country analysis. *Telecommunications Policy*, 34(5–6), 323–340. <https://doi.org/10.1016/j.telpol.2010.01.003>
- Applebee, A. (2002). Academic research on the Internet: Options for scholars and libraries. *Online Information Review*, 26(2), 122–129. <https://doi.org/10.1108/oir.2002.26.2.122.1>
- Archibugi, D., Filippetti, A., & Frenz, M. (2013). Economic crisis and innovation: Is destruction prevailing over accumulation? *Research Policy*, 42(2), 303–314. <https://doi.org/10.1016/j.respol.2012.07.002>
- Balioune-Lutz, M. (2003). An analysis of the determinants and effects of ICT diffusion in developing countries. *Information Technology for Development*, 10(3), 151–169. <https://doi.org/10.1002/itdj.1590100303>
- Barro, R. J., & Lee, J. W. (2013). A new data set of educational attainment in the world, 1950–2010. *Journal of Development Economics*, 104(15902), 184–198. <https://doi.org/10.1016/j.jdeveco.2012.10.001>
- Benoit, W. L., & Hansen, G. J. (2004). The changing media environment of presidential campaigns. *Communication Research Reports*, 21(2), 164–173. <https://doi.org/10.1080/08824090409359978>
- Best, M. L., & Wade, K. W. (2009). The Internet and democracy: Global catalyst or democratic dud? *Bulletin of Science, Technology & Society*, 29(4), 255–271. <http://journals.sagepub.com/doi/pdf/10.1177/0270467609336304> <https://doi.org/10.1177/0270467609336304>
- Black, S. E., & Lynch, L. M. (2001). How to compete: The impact of workplace practices and information technology on productivity. *The Review of Economics and Statistics*, 83(3), 434–445. <https://doi.org/10.1162/00346530152480081>
- Caso, R., & Guarda, P. (2019). Copyright overprotection versus open science: The role of free trade agreements. In Lillian Corbin & Mark Perry (eds), *Free trade agreements* (pp. 35–51). Springer.
- Chavula. (2013). Telecommunications development and economic growth in Africa. *Information Technology for Development*, 19(1), 5–23. <https://doi.org/10.1080/02681102.2012.694794>
- Choi, C., & Yi, M. H. (2009). The effect of the Internet on economic growth: Evidence from cross-country panel data. *Economics Letters*, 105(1), 39–41. <https://www.sciencedirect.com/science/article/pii/S0165176509001773?via%3DIihub> <https://doi.org/10.1016/j.econlet.2009.03.028>
- Choi, I. (2001). Unit root tests for panel data. *Journal of International Money and Finance*, 20(2), 249–272. [https://doi.org/10.1016/S0261-5606\(00\)00048-6](https://doi.org/10.1016/S0261-5606(00)00048-6)
- Chung, J. (2008). Comparing online activities in China and South Korea: The internet and the political regime. *Asian Survey*, 48(5), 727–751. <https://doi.org/10.1525/AS.2008.48.5.727>
- Cutler, A., & Zhao, G. (2001). Pert-perfect random tree ensembles. *Computing Science and Statistics*, 33, 490–497.
- Dalrymple, K. E., & Scheufele, D. A. (2007). Finally informing the electorate? How the Internet got people thinking about presidential politics in 2004. *Harvard International Journal of Press/Politics*, 12(3), 96–111. <https://doi.org/10.1177/1081180X07302881>
- Fritsch, M., & Franke, G. (2004). Innovation, regional knowledge spillovers and R&D cooperation. *Research Policy*, 33(2), 245–255. [https://doi.org/10.1016/S0048-7333\(03\)00123-9](https://doi.org/10.1016/S0048-7333(03)00123-9)
- Gao, Y., Zang, L., Roth, A., & Wang, P. (2017). Does democracy cause innovation? An empirical test of the popper hypothesis. *Research Policy*, 46(7), 1272–1283. <https://doi.org/10.1016/j.respol.2017.05.014>
- Gao, Y., Zang, L., & Sun, J. (2018). Does computer penetration increase farmers' income? An empirical study from China. *Telecommunications Policy*, 42(5), 345–360. <https://doi.org/10.1016/j.telpol.2018.03.002>
- García, C. B., García, J., Martín, M. M. L., & Salmerón, R. (2015). Collinearity: Revisiting the variance inflation factor in ridge regression. *Journal of Applied Statistics*, 42(3), 648–661. <https://doi.org/10.1080/02664763.2014.980789>
- Genuer, R., Poggi, J.-M., & Tuleau-Malot, C. (2010). Variable selection using random forests. *Pattern Recognition Letters*, 31(14), 2225–2236. <https://doi.org/10.1016/j.patrec.2010.03.014>
- Gurău, C. (2002). E-banking in transition economies: The case of Romania. *Journal of Financial Services Marketing*, 6(4), 362–378. <https://doi.org/10.1057/palgrave.fsm.4770065>
- Higón, D. A. (2012). The impact of ICT on innovation activities: Evidence for UK SMEs. *International Small Business Journal: Researching Entrepreneurship*, 30(6), 684–699. <http://journals.sagepub.com/doi/pdf/10.1177/0266242610374484> <https://doi.org/10.1177/0266242610374484>
- Hobday, M. (2005). Firm-level innovation models: Perspectives on research in developed and developing countries. *Technology Analysis & Strategic Management*, 17(2), 121–146. <https://doi.org/10.1080/09537320500088666>
- Holt, L., & Jamison, M. (2009). Broadband and contributions to economic growth: Lessons from the US experience. *Telecommunications Policy*, 33(10–11), 575–581. <https://doi.org/10.1016/j.telpol.2009.08.008>

- Hwang, W.-S., & Shin, J. (2017). ICT-specific technological change and economic growth in Korea. *Telecommunications Policy*, 41(4), 282–294. <https://doi.org/10.1016/j.telpol.2016.12.006>
- Johne, F. A., & Snelson, P. A. (1988). Success factors in product innovation: A selective review of the literature. *Journal of Product Innovation Management*, 5(2), 114–128. <https://doi.org/10.1111/1540-5885.520114>
- Kafourous, M. I. (2006). The impact of the Internet on R&D efficiency: Theory and evidence. *Technovation*, 26(7), 827–835. <https://doi.org/10.1016/j.technovation.2005.02.002>
- Karamti, C. (2016). Measuring the impact of ICTs on academic performance: Evidence from higher education in Tunisia. *Journal of Research on Technology in Education*, 48(4), 322–337. <https://doi.org/10.1080/15391523.2016.1215176>
- Koellinger, P. (2008). The relationship between technology, innovation, and firm performance—Empirical evidence from e-business in Europe. *Research Policy*, 37(8), 1317–1328. <https://www.sciencedirect.com/science/article/pii/S004873330800108X?via%3Dihub> <https://doi.org/10.1016/j.respol.2008.04.024>
- Kumar, B. T. S., & Manjunath, G. (2013). Internet use and its impact on the academic performance of university teachers and researchers: A comparative study. *Higher Education*, 3(3), 219–238. (220). <https://doi.org/10.1108/HESWBL-09-2011-0042>
- Lehmann, E. E., & Seitz, N. (2016). Freedom and innovation: A country and state level analysis. *Journal of Technology Transfer*, 42, 1–21. <https://doi.org/10.1007/s10961-016-9478-3>
- Levendis, J., & Lee, S. H. (2013). On the endogeneity of telecommunications and economic growth: Evidence from Asia. *Information Technology for Development*, 19(1), 62–85. <https://doi.org/10.1080/02681102.2012.694793>
- Malaquias, R. F., & Hwang, Y. (2017). The role of information and communication technology for development in Brazil. *Information Technology for Development*, 23(1), 179–193. <https://doi.org/10.1080/02681102.2016.1233854>
- Malerba, F., & Mani, S. (2002). Sectoral systems of innovation and production in developing countries: Actors, structure and evolution. *Research Policy*, 31(2), 247–264. [https://doi.org/10.1016/S0048-7333\(01\)00139-1](https://doi.org/10.1016/S0048-7333(01)00139-1)
- Marquardt, D. W. J. T. (1970). Generalized inverses, ridge regression, biased linear estimation, and nonlinear estimation. *Technometrics*, 12(3), 591–612. <https://doi.org/10.1080/00401706.1970.10488699>
- Marshall, M. G., Jaggers, K., & Gurr, T. R. (2015). Polity IV project: Dataset users' manual.
- Mcauliffe, R. E. (2015). *Diminishing marginal utility*. John Wiley & Sons, Ltd.
- Menon, S. (2011). Linking generativity and disruptive innovation to conceptualize ICTs. *Internet Research*, 21(3), 347–361. (315). <https://doi.org/10.1108/10662241111139345>
- Montgomery, D., Peck, E., & Vining, G. J. N. Y. (1982). Introduction to linear regression analysis John Wiley.
- North, D. C., & Thomas, R. P. (1976). The rise of the Western world: A new economic history. *Contemporary Sociology*, 27(4), 38.
- OECD. (2000). *A new economy? The changing role of innovation and information technology in growth*. OECD Publishing.
- Olló-López, A., & Aramendía-Muneta, M. E. (2012). ICT impact on competitiveness, innovation and environment. *Telematics and Informatics*, 29(2), 204–210. <https://doi.org/10.1016/j.tele.2011.08.002>
- Qureshi, S. (2013). Networks of change, shifting power from institutions to people: How are innovations in the use of information and communication technology transforming development? *Information Technology for Development*, 19(2), 97–99. <https://doi.org/10.1080/02681102.2013.789151>
- Qureshi, S. (2015). Are we making a better world with information and communication technology for development (ICT4D) research? Findings from the Field and Theory Building. *Information Technology for Development*, 21(4), 511–522. <https://doi.org/10.1080/02681102.2015.1080428>
- Rød, E. G., & Weidmann, N. B. (2015). Empowering activists or autocrats? The Internet in authoritarian regimes. *Journal of Peace Research*, 52(3), 338–351. <https://doi.org/10.1177/0022343314555782>
- Roztocki, N., & Weistroffer, H. R. (2016). Conceptualizing and researching the adoption of ICT and the impact on socio-economic development. *Information Technology for Development*, 22(4), 541–549. <https://doi.org/10.1080/02681102.2016.1196097>
- Sawhney, M., Verona, G., & Prandelli, E. (2005). Collaborating to create: The Internet as a platform for customer engagement in product innovation. *Journal of Interactive Marketing*, 19(4), 4–17. <https://www.sciencedirect.com/science/article/pii/S1094996805700785?via%3Dihub> <https://doi.org/10.1002/dir.20046>
- Sell, S. K. (2013). Revenge of the “nerds”: Collective action against intellectual property maximalism in the global information age. *International Studies Review*, 15(1), 67–85. <https://doi.org/10.1111/misr.12021>
- Soto-Acosta, P., Colomo-Palacios, R., & Popa, S. (2014). Web knowledge sharing and its effect on innovation: An empirical investigation in SMEs. *Knowledge Management Research & Practice*, 12(1), 103–113. <https://doi.org/10.1057/kmrp.2013.31>
- Steinmueller, W. E. (2001). ICTs and the possibilities for leapfrogging by developing countries. *International Labour Review*, 140(2), 193–210. <https://doi.org/10.1111/j.1564-913X.2001.tb00220.x>
- Teorell, J., Dahlberg, S., Holmberg, S., Rothstein, B., Hartmann, F., & Svensson, R. (2015). *The quality of government standard dataset, version jan15*. The Quality of Government Institute.
- Warschauer, M. (2004). *Technology and social inclusion: Rethinking the digital divide*. MIT press.
- Weiser, P. J. (2003). The Internet, innovation, and intellectual property policy. *Columbia Law Review*, 103(3), 534. <https://doi.org/10.2307/1123718>

- Whitacre, B., Gallardo, R., & Strover, S. (2014). Does rural broadband impact jobs and income? Evidence from spatial and first-differenced regressions. *The Annals of Regional Science*, 53(3), 649–670. <https://doi.org/10.1007/s00168-014-0637-x>
- Zheng, Y., Hatakka, M., Sahay, S., & Andersson, A. (2018). Conceptualizing development in information and communication technology for development (ICT4D). *Information Technology for Development*, (1), 1–14. <https://doi.org/10.1080/02681102.2017.1396020>
- Zhu, K., Kraemer, K. L., & Xu, S. (2006). The process of innovation assimilation by firms in different countries: A technology diffusion perspective on e-business. *Management Science*, 52(10), 1557–1576. <https://doi.org/10.1287/mnsc.1050.0487>
- Zuppo, C. M. (2012). Defining ICT in a boundaryless world: The development of a working hierarchy. *International Journal of Managing Information Technology*, 4(3), 13–22. <https://doi.org/10.5121/ijmit.2012.4302>