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Article

How (when) does technological innovation improve government effectiveness? An empirical investigation with cross-national evidence

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Abstract

How to understand the impacts of government effectiveness (GE) on technological innovation has received full attention. But in turn, it is still a puzzle how technological innovation promotes GE. With the intention of providing rigorous empirical evidence to fill the gap, authors efficiently selected variables based on novel machine learning and analyzed the influence mechanism of technological innovation on GE through different models, using panel data from global countries over 20 years. The investigation has revealed that the relationship between technological innovation and GE is not a simple linear relation but a more complicated inverted U-shaped relation. We also distinguished the impacts of technological innovation on GE in countries with diverse democratic and developing levels. This pioneering work has provided new insights to our understanding of innovation diffusion and determinants of GE.

Key words: technological innovation; government effectiveness; machine learning; inverted U-shaped; instrumental variable

1. Introduction

The innovation of modern science and technology has greatly changed the human behavioral pattern, making our society more convenient by improving working efficiency, also influencing the organizational life pattern. In the case of government, technological innovation is one of the core determinants in public sector reorganization because of its influence on process re-engineering and effectiveness reform. Scholars have examined specifically the relationship between technological innovation and government effectiveness (GE), while most of the extant researches focus on discussing whether government measures such as official subsidy and grants are conducive to innovation or the diffusion of it (King et al. 1994; Park 2014). Research on European countries shows that the government quality plays a vital role in the national innovation system (Rodríguez-Pose and Di Cataldo 2014). The latest research has also pointed out that a country with high GE is very helpful in improving national innovation capacity (Zhang et al. 2019a).

But in a general context, how does universal innovation in turn influence GE? There are some studies based on specific technological innovations, which, for example, indicate that the application of copier, telephone, or Internet to a public organization has greatly improved GE or governance performance (Brown 2001; Melitski 2003). Researches on spillover effects of innovation have shown that the increased national capability stimulates policy imitations in peripheral countries. For instance, continuous innovation contributes to the overall optimization of social development policies (Chena et al. 2008), and improved innovation capacity helps to promote R&D investment cooperation among countries (Fritsch and Franke 2004). Of course, the geographical diffusion of regional innovation spillovers is also affected by strong distance decay effects (Rodríguez-Pose and Crescenzi 2008).

Scholars above mainly focused on the spillover effects of innovation in Europe or other developed countries and the analysis of the impact of innovation capacity on business organizations' performance. Meanwhile, some researches have explored the spillover effects of innovation on specific government policies, while ignoring how innovation can improve government performance at the macro level. We attempted to fill the gap based on rigorous empirical results by studying the panel data from 117 countries covering the period from 1995 to 2014. In addition, this article confirms twenty-eight control variables based on innovation diffusion and related literature. The authors then efficiently selected twelve variables through machine learning so that we could precisely analyze the mechanism of innovation on GE in different models. Our findings reveal that the relationship between innovation and GE is not presented as a simple linear shape but a more complicated inverted U-shaped curve.

The article consists of six parts: relevant literature and theoretical framework are discussed in Section 2. Section 3 describes the research design, including data description, variables screening, and model construction. The Section 4 gives the results of the positive analysis. Section 5 provides the robustness test and Section 6 is the conclusion along with the discussion.

2. Literature review and hypothesis development

The impact of technological innovation on organizations has long-attracted scholars' attention. For instance, Markus and Robey (1988) systematically conducted a theoretical and factual analysis on the relationship between information technology (IT) and organizational change and concluded that the application of the Internet had promoted decentralization in organizations with uncertain environments. Robey et al. (2013) also performed a comparative analysis between the sociotechnical and the socio-material perspectives so as to explore the influence of IT on initiatives of organizational changes. What's more, Leonardi (2007), Pinsonneault and Kraemer (2002), considering how IT is applied to organizational actions, held the view that the informational capabilities of a new technology would be significantly beneficial to the changes of organizations.

Overall, in previous studies, scholars mainly analyzed the impact of technological innovation on organizations from the following aspects. First, innovation application contributes to the improvement of organization performance (Leavitt 1965; Perrow 1967). Orlikowski, a preeminent scholar in this field, pointed out that the interactions between technology and organizations had an important impact on the development and design of organizations' structure (Orlikowski 2007, 2010). Second, the application of innovation also contributes to the change of organizations' re-innovation and deployment. Henderson and Clark (1990) emphasized that as a driving element of organizational change within the company, technological innovation remarkably affected the systematic format, structure, and scale of organizational reformation. Grimpe (2016) further put forward that the application of innovation made contributions to a company's reform and would promote the expansion of organization scale. Taking Schumpeter's hypothesis as an example, it pointed out that innovation would effectively promote business expansion (Kirchhoff and Phillips 1989). Third, modern technology reduces the overheads of organizations. Borghans and Weel (2006) argued that if IT increased labor productivity, correspondingly the requirements for workers' skills may also be raised, which can help improve or enhance the professional level of the organization's human resources. Bresnahan et al. (2002) also held a similar view that technological innovation led to a reduction in the cost of access to knowledge and information, which in turn improved the competitiveness of organizations. Meanwhile, in the cases of most domestic firms in developing countries, innovation is a vital tool for organizations to survive and catch up in the fierce market competition (Fan 2006; Sok and O'Cass 2011). Typically in those knowledge-intensive industries, innovation plays an indispensable role in firms' corporate sustainability (Taherparvar et al. 2014; Urgal et al. 2013).

Innovation not only exerts a major impact on the performance of business organizations but also counts in public sectors. Government performance or effectiveness is the key focus of academic researches and public criticisms. However, to date, no clear and conclusive evaluation system has been built for government performance. There are many terms conceptually close to the concept of GE in academic researches, such as the quality of government, governance efficiency, the quality of public policies, and their implementation. But these various conceptual expressions differ only slightly. This article draws on the researches of Magalhães (2014) and Lee and Whitford (2009) and refers to the definition of GE given by World Bank:

GE captures the perceptions of public service quality, the quality of civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies (Kaufmann et al. 2008; Kaufmann 2011).

It points out emphatically that the administrative subject, while utilizing low investment of administrative resources, can achieve the goal of the government and optimize the allocation of public resources. Since the end of the twentieth century, countries all over the world have paid attention to improving GE and banishing red tape through various administrative tools or reforms (Lane 1997; Light 1998; Moynihan 2008). Along with the steady development of economy and society, GE is also improving step-by-step.

How does innovation improve GE? In reality, scholars often evaluate GE in three ways: economy, efficiency, and effectiveness (Talbot 2010; Wallner 2008). Extant studies have demonstrated that in the first place, technological innovation can advance the economic development of organizations. To be specific, the application of technology helps government in improving the management level, reduces the cost of economic input, and maintains a relatively fixed quantity as well as quality of public goods or services (Huang et al. 2016). In the second place, technological innovation contributes to the advancement in productive efficiency and allocation efficiency of public services. For example, with the help of computer networks, the service level and efficiency of public hospitals and libraries have been improved (Huang and Guo 2017; Mccullough 2010). Meanwhile, it has been questioned whether the budgetary allocation for various government public services (such as national defense, social welfare, education, and healthcare) is consistent with people's preferences and can be close to the Pareto-optimality, which means that the allocation of resources can meet the greatest interests of most people. For example, big data innovation has created new conveniences for the government to identify the different preferences of communities (Gunasekaran et al. 2016). Studies on European countries also showed that an e-government significantly increases the effectiveness of public sector services (Scott et al. 2016). Finally, GE is used as a measure only for public goods or services that can be quantified or monetized. However, many public goods or services are difficult to define in nature and are even harder to quantify. In this case, the scholars examined whether the government's public policies or services are capable of bringing about improvements in social welfare, such as national healthcare, environmental quality monitoring, and so on, for this has become an important indicator of GE. The innovation of modern technology, in reality, is contributive to the government in achieving these goals more effectively (Llewellyn 2010).

In general, technological innovation capacity is closely related to political development and public sector reform. Nowadays, military R&D (which causes huge controversy), modern science, and new media technology are able to establish a newer and closer relationship between the government and citizens than ever before. And technological application and innovation diffusion theory are used to analyze the development of production technology in enterprises and other fields (Goslar 1987; Oliveira and Martins 2011). More and more government departments realize the benefits of modern technology. For instance, the emergence of modern printing technology significantly improved the efficiency of organizations in dealing with official documents. And the video conference system substantially enhanced the efficiency of communication and dissemination of information among departments.

However, it is clear that most of the studies above focused on the issue that innovation promotes organizational change. Some researchers pointed out that organizational change or government reform did not necessarily mean better organizational performance (Burke and Litwin 2016). At the same time, most extant studies focused on the impact of innovation on GE in European countries or the impact of IT innovation on GE. But how do general national innovation and its application affect GE? On the basis of the analysis above, this article puts forward the following research hypotheses to validate the impact of technological innovation capacity on GE. First of all, we propose Hypothesis 1 as follows:

H1: Ceteris paribus, national innovation capacity has a positive impact on the development of GE.

Meanwhile, since Simon Kuznets put forward the concept of the 'inverted U curve' in 1955 (Kuznets 1955), it has become a hot topic for scholars to explore whether the inverted U-shaped curve is presented among different variables in social and economic developments (Zang et al. 2019b). Scholars have explored the inverted U curve of technological innovation in the environmental field (Baiardi 2014), which can further explain the dynamic process of variables' relationship with the growth of technological innovation. So is there a similar relationship between innovation capacity and GE, which has not been paid enough attention before? Thus Hypothesis 2 is proposed as follows:

H2: Ceteris paribus, there is an inverted U-shaped relationship between innovation capacity and GE. That is to say, innovation capacity first increases the level of GE and then decreases it.

Some studies have noticed that GE is influenced by a variety of factors (Hauner and Kyobe 2010; Rayp and Sijpe 2007), such as the application ability of innovative technologies (Welch and Feeney 2014), the education level of civil servants, the structure of departments, and economic developments and bureaucratic cultures (Garciasanchez et al. 2013). Will other social and cultural factors affect the role of technological innovation capacity in GE? Extant studies have shown that technological innovation can be used differently in countries with different political systems. Therefore, taking the political system as an example, this article develops Hypothesis 3 as follows:

H3: Ceteris paribus, the higher a country's democratization level, the greater the improvement of innovation capacity on the GE.

3. Research design

3.1 Independent variables and dependent variables

Innovation has a close relationship with patents. Yet, patent data are often included in researches by scholars so as to estimate the present situation of science and technological innovation (Acs et al. 2002; Lanjouw and Schankerman 2004). To build the proxy of national innovation capacity, this study takes the patent data of the US National Bureau of Economic Research (NBER) as an independent variable and contains the detailed information of patents granted by the US Patent and Trademark Office (USPTO) from 1995 to 2014. Compared with the World Intellectual Property Office, we prefer data from USPTO, because it has less data missing. Meanwhile, patents in different countries may represent different levels of innovation, which means that the patents granted in a certain country may not be innovative enough in another and might not be competent enough to be accepted by foreign patent offices. Since the USA is the world's largest technology consumer, previous studies have generally considered that almost all important innovations have been patented by the US Patent Office (Acharya and Subramanian 2009; Griffith et al. 2006; Hsu et al. 2014). Therefore, the number of patents applied by the USPTO is sufficient to measure the innovation capacity of other countries, which has been widely used in peer-reviewed articles (Gao et al. 2017).

GE is a dependent variable used in this article. It comes from the Worldwide Governance Indicators and it is integrated into synthesized responses on the quality of public service and official system. Scores of GE lie between -2.5 and 2.5, with higher scores corresponding to better effectiveness (Kaufmann 2011).

3.2 Machine learning and control variable screening

An analysis of the social, political, as well as economic theories of previous studies can help to obtain the main variables that are relevant to GE (Hauner and Kyobe 2010; Rayp and Sijpe 2007). Due to the fact that too many variables in existing researches have influence on GE, selecting the most suitable variables for model fitting is quite challenging. Random forest or random decision forest is a common-used and flexible method in feature selection, which can effectively select a more relevant group of control variables. Therefore, it helps to enhance the explanatory power of the model and make our estimation among variables more accurate.

Random forest, which was proposed by Breiman Leo and Adele Cutler of the University of California at Berkeley in 2001, is an efficient feature selection method for machine learning (Cutler and Zhao 2001). It is operated by constructing a large number of decision trees in the training process. In addition, it also generates the classes (classification) or mean prediction (regression) of the individual trees and can be used for other tasks such as classification, regression, survival analysis, and feature selection (Genuer et al. 2010). Random forests can better predict and analyze the importance of different variables in a set of unbalanced panel data, which are represented by the increasing values of mean square error (MSE). Thus, the authors have created the sequence of variables based on their increasing values of MSE, which have been acquired through its establishment in the random forest model that contains all controlled variables and independent ones.

Table A1 in the Online Appendix displays the top 28 variables that are most relevant to GE. Table A2 in the Online Appendix shows the results of collinear test for the variables above. At first, we excluded variables (variance inflation factor (VIF) > 10) that have a collinearity problem, such as the log of R&D per capita, rule of law, government integrity, freedom of the press, Economic World Institutional quality ranking, and press freedom index. Compared with urban population (in per cent of total), the log of population density can describe the population structure more accurately. The variable of cultural diversity, which has the greatest impact on the GE, has been included in the model. The data of labor freedom variable have more than two-thirds of missing values so that should be excluded as well. Internet users (per 100 people) and the log of the patent grants are very similar, so the former can be used as exogenous instrumental variables (IVs).

Table 1. Descriptive statistics for primary selected variables.

Variable	Observation	Mean	SD	Minimum	Maximum
GE	1,844	0.1299	0.9637	−2.0309	2.4297
The log of patent grants	1,561	3.4902	2.8584	0	12.2663
The sum of exports and imports of goods and services of GDP (%)	2,255	81.3096	43.1492	15.5803	439.6567
Log of GDP per capita	2,281	8.6376	1.4339	5.8826	11.4251
Log of population density (people per square kilometer of land area)	2,278	4.1212	1.3881	0.3915	8.9537
Political stability	1,844	−0.0730	0.8895	−2.3901	1.6681
Level of democracy (Freedom House/Imputed Polity)	2,283	6.7351	3.0721	0	10
Economic freedom index	2,244	61.0316	10.4682	21.4	89.40501
Political corruption	1,945	0.4918	0.2909	0.0098	0.9434
Cultural diversity	2,225	0.2875	0.2028	0	0.7328
Telephone lines (per 100 people)	2,276	20.7409	18.6014	0	74.7625
Political imprisonment	1,916	1.2171	0.8238	0	2
Tax burden	1,951	72.4530	14.9415	29.8	99.9
The log of secure Internet servers (per 1 million people)	1,444	2.5412	2.7576	−4.9316	8.0754
The quality of government regulation	1,722	0.1590	0.9361	−2.2102	2.2474
Internet users (per 100 people)	2,283	23.2156	26.9151	0	98.16

Table 2. Results of multicollinearity test.

Variable	VIF	Square root VIF	Tolerance	R^2
The log of patent grants	3.22	1.79	0.3105	0.6895
The sum of exports and imports of goods and services	1.42	1.19	0.7025	0.2975
Log of GDP per capita	9.70	3.12	0.1030	0.8970
Log of population density	1.47	1.21	0.6817	0.3183
Political stability	3.43	1.85	0.2911	0.7089
Level of democracy	3.30	1.82	0.3035	0.6965
Economic freedom index	3.36	1.83	0.2973	0.7027
Political corruption	3.88	1.97	0.2575	0.7425
Cultural diversity	1.35	1.16	0.7421	0.2579
Telephone lines	4.97	2.23	0.2013	0.7987
Tax burden	2.48	1.58	0.4027	0.5973
Political imprisonment	2.01	1.42	0.4981	0.5019
The log of secure Internet servers	7.81	2.79	0.1280	0.8720
Mean VIF	3.72			

We finally controlled the following potential determinants of GE based on the results of machine learning and extant literature: First, per capita gross domestic product (GDP) is a visible variable referring to the degree of prosperity of a country. Furthermore, the authors also considered setting the sum of exports and imports of goods and services (in per cent of GDP) as the other controlled variables. All data here are borrowed from the World Bank. In addition, this article also uses the economic freedom index, which comes from the Heritage Foundation and *Wall Street Journal*, to measure the vibrant level of one country. From the political dimension, we also take variables like political stability (World Governance Indicators), political corruption (Transparency International), level of democracy (Freedom House/Imputed Polity), and political imprisonment (Human Rights Watch) into consideration. This article also uses tax burden data from the World Bank, as well as the data involving cultural diversity, telephone lines (per 100 people), and the log of secure Internet servers (per 1 million people).

3.3 Non-equilibrium data mining

Based on the above analysis and the results from the random forest, the authors constructed this series of variables from 1995 to 2014 as the panel data. Although the USPTO data set contains data from 224 countries/regions, a large portion of values (10 per cent or more for any year) for some countries/regions are missing. To ensure the quality of the data set, we mainly examined the missing degree of earlier-mentioned variables of these 156 countries (see Table A3 in the Online Appendix for details). The authors took the third quartile (17.43 per cent) missing data as a critical parameter to further exclude some countries (if the degree of data missing in a country is higher than 17.43 per cent). Figure A1 in the Online Appendix describes the histogram of the proportion of missing data among different countries. It shows that the degree of data-missing of some countries is around or even higher than 10 per cent; therefore, the authors then removed those countries from the study and finally collected the panel data of 117 countries from 1995 to 2014.

The descriptive statistics of all the variables are presented in Table 1. It can be seen that the number of observations (or data points) is quite different among variables. The ways of different variables calculated in this study are basically consistent with those from the World Bank, suggesting that the selected countries are highly representative.

Figure A2 in the Online Appendix describes the relationship between technological innovation and GE by the scatter plot and the polynomial curve fit. In addition, it also shows that, in general, a positive correlation, sometimes an inverted U curve, can be seen between technological innovation and GE. In the following part, the impact mechanism between these two variables will be thoroughly analyzed, based on the fixed effects (FE) model.

3.4 Model construction

To further examine our earlier-stated hypotheses and explore the causal relationship between technological innovation and GE, the authors established the following different regression models.

3.4.1 Multiple linear regression model

First, the multiple linear regression model will be used to explore this relationship among variables. We can extract as much information about different variables as possible using this model. Meanwhile, the magnitude of those coefficients through this model can reflect the changing trends of our research subject from 1995 to 2014, based on which we established the following regressive mathematical model.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p + \varepsilon \qquad (1)$$

$$\varepsilon \sim N(0, \sigma^2)$$

where β is the regression coefficients; ε represents residuals that follow a normal distribution. This article will use the maximum likelihood estimator to estimate these regression coefficients.

When considering the time (year) trend and heteroskedasticity, the estimated method of feasible generalized least squares (FGLS) is the best choice in this study. Compared with other regression results, FGLS generated a better solution than the general ordinary least squares (OLS) estimated method to deal with the time trend and heteroskedasticity.

3.4.2 FE model

The endogenous problem caused by omitting the explaining variables is always an issue in the regression model. On the basis of Equation (1), the lagged patent counts term is added in Equation (2). The lag term in the time series was comprised of so much information before we can explain a few changes of the dependent variables at the current time. This model can therefore reduce the extent of the endogenous problem and increase the power of its explanations. The authors also established the following FE model:

$$y_{it} = \beta_0 + \beta_1 x_{it} + \beta_2 z_{it} + \alpha_i + \xi_t + \varepsilon_{it} \qquad (2)$$

where i denotes any of the countries in our sample and $i = 1, \ldots, 117$; t denotes the year and $t = 1, \ldots, 20$; y_{it} represents the explained variable; x_{it} is a vector of time-variant explanatory variable; z_{it} is the matrix of control variables; β denotes the coefficients to be estimated; α_i is the fixed country effects, which is potentially correlated with x_{it}; ξ_t is the fixed time (year) effects; and ε_{it} denotes the error term.

In the statistics, there are many estimated methods to calculate the coefficients of the variables. Only when considering the fixed country effects, we used the estimated method of least square dummy variables to regress the main model. In this article, the authors compared the results of different kinds of regression estimated methods with diverse FE (time, country, or both).

4. Empirical results

To overcome the intense correlation among the variables and to ensure that the correlation coefficient estimated in the model is free of distortion or inaccuracy, the authors, first, performed a multicollinearity test. Table 2 indicates that the VIF values of all the variables are less than ten, suggesting that multicollinearity does not exist among variables. Thus, we can use all the variables to conduct subsequent analysis in the multiple linear regression model.

When the panel data are analyzed, the unit root test is necessary to test the stationarity of time series. In this study, a Fisher-type test is typically used since our panel data are unbalanced. Table A5 in the Online Appendix shows that, according to the four methods of Fisher's unit-root test (Choi 2001), results are statistically significant ($P = 0.000$). So we can reject the null hypothesis that the panel data used in this article are unstable. Therefore, the analysis of the panel data model with the log of patent grants as an independent variable is feasible and does not produce spurious regression.

4.1 Results of multiple linear regression

In Table 3, we compared the regression results which added the variable of the square log of patent grants with those who did not in Models 1 and 2, respectively, while Model 3 shows FGLS regression results. Model 4 describes the average impact of technological innovation on the efficiency of governments in different regions.

Regression results of different models in Table 3 show that technological innovation generates a significantly positive effect on GE. Thus Hypothesis 1 is confirmed. Meanwhile, results of other variables also show that the economic development level of a country, population density, political stability, the level of democratization, economic freedom, and cultural diversity are positively correlated with public sector performance, which is in line with the existing research results (Perry and Christensen 2015; Pierre 2003; Wholey 2007). In the meantime, political corruption, government imprisonment, and high tax burden will impose negative impacts on GE, which is also consistent with the extant research results (Burman and Phaup 2012; Helland and Sørensen 2015; Rose-Ackerman and Palifka 2016).

Model 2 of Table 3 shows that the square patent grants have a significantly negative correlation with GE, which means the influence imposed by technological innovation on GE presents an inverted U-shaped feature. This shows that as a country's diffusion of technological innovation has been gradually improved, the impact of its technological innovation on GE increases at first and then gradually decreases. In other words, technological innovation exerts a diminishing marginal effect on the improvement of GE. Thus, Hypothesis 2 is testified. This shows that a simple linear relationship in the traditional view does not exist between technological innovation and GE.

The geographical, cultural, and historical factors of different countries also affect the performance promotion of public sectors in different countries. As for different regions, technological innovation has a more positive impact on GE in the Middle East, North Africa, and South Asia but no positive impact in other countries and even a negative effect on the GE of Latin America and Caribbean countries. Therefore, further exploration of this phenomenon is needed.

4.2 Results of FE model

This part, based on the FE model, takes account of time effects and country effects to examine the impact of technological innovation on GE more precisely. In Table 4, Model 1 shows the original and simple regression with variables of technological innovation and GE only. Although the R^2 index is small, technological innovation indeed has a significantly positive effect on GE. Considering the controlled variables, Models 2 and 3 demonstrate that regarding the

Table 3. Results of multiple linear regression.

Variables	Model 1 Mult-reg	Model 2 Mult-reg	Model 3 FGLS	Model 4 Mult-reg
The log of patent grants	0.0484***	0.0814***	0.0426***	0.0290***
	(0.01)	(0.01)	(0.00)	(0.01)
The square log of patent grants		−0.0039** (0.00)		
The sum of exports and imports of goods and services	0.0012***	0.0009*	0.0009***	0.0005
	(0.00)	(0.00)	(0.00)	(0.00)
Log of GDP per capita	0.0807**	0.0651*	0.0790***	0.1025***
	(0.03)	(0.03)	(0.02)	(0.03)
Log of population density	0.0218*	0.0292**	0.0261***	0.0100
	(0.01)	(0.01)	(0.01)	(0.01)
Political stability	0.1477***	0.1514***	0.1392***	0.1564***
	(0.02)	(0.02)	(0.01)	(0.02)
Level of democracy	0.0268***	0.0203*	0.0214***	0.0428***
	(0.01)	(0.01)	(0.00)	(0.01)
Economic freedom index	0.0329***	0.0336***	0.0295***	0.0310***
	(0.00)	(0.00)	(0.00)	(0.00)
Political corruption	−0.7448***	−0.7487***	−0.7695***	−0.7485***
	(0.07)	(0.07)	(0.04)	(0.07)
Cultural diversity	0.0069	0.0057	0.1420***	−0.0230
	(0.06)	(0.06)	(0.04)	(0.06)
Telephone lines	0.0002	0.0006	−0.0002	−0.0010
	(0.00)	(0.00)	(0.00)	(0.00)
Tax burden	−0.0168***	−0.0169***	−0.0162***	−0.0168***
	(0.00)	(0.00)	(0.00)	(0.00)
Political imprisonment	−0.1363***	−0.1271***	−0.1232***	−0.1076***
	(0.02)	(0.02)	(0.01)	(0.02)
The log of secure Internet servers	−0.0001	0.0030	0.0327**	−0.0033
	(0.01)	(0.01)	(0.01)	(0.01)
East Asia and Pacific				—
Europe and Central Asia				−0.1035**
				(0.04)
Latin America and Caribbean				−0.2812***
				(0.04)
Middle East and North Africa				0.0810
				(0.05)
South Asia				0.0453
				(0.07)
Sub-Saharan Africa				−0.1681**
				(0.05)
Constant	−1.3089***	−1.2322***	−1.0920**	*−1.2097***
	(0.28)	(0.20)	(0.26)	(0.27)
Observation	560	560	560	560
Number of country	117	117	117	117
Time trends	No	No	Yes	No
R^2	0.931	0.932	—	0.941

Notes: Standard errors are in parentheses; *, ** and *** denote significance levels of 5%, 1%, and 0.1%, respectively.

results from the FE model or the random effect model, the innovation has a prominent and consistent impact on GE. However, according to the Hausman test, the FE model is much more precise in this article. It can be seen from Model 4 that technological innovation not only has current positive effects in the short term but also remarkable lagged effects on GE in the long term.

This is mainly due to two factors. First, compared with the rapid adoption of the latest technologies by enterprises, the application of new technologies by the government is relatively lagging behind. Second, the diffusion of technological innovation between different countries makes it difficult for some governments to obtain the convenience of scientific and technological innovation.

Comparing Models 2 and 5 in Table 4, the results show that no matter the time effect is controlled or not, the effect of technological innovation on GE is relatively stable, and the effect of other control variables on GE here is also consistent with the results in Table 3, all of which further demonstrate that the findings of this article present high validity and reliability.

4.3. Comparing the effects of innovation on different democracies

The difference of technological innovation in political systems is often distinct since countries have different historical and cultural backgrounds. Moreover, previous studies have shown that the same technological innovation has various application effects in countries with different political systems. With regard to Internet technology, for example, it may become a tool for assisting governments to

Table 4. Results of FE model.

Variables	Model 1 FE	Model 2 FE	Model 3 RE	Model 4 FE	Model 5 FE
The log of patent grants	0.0353***	0.0355***	0.0517***		0.0350***
	(0.01)	(0.01)	(0.01)		(0.01)
The lag of log of patent grants				0.0444***	
				(0.01)	
The sum of exports and imports of goods and services		−0.0009*	−0.0014***	−0.0012**	−0.0001
		(0.00)	(0.00)	(0.00)	(0.00)
Log of GDP per capita		0.2103***	0.2022***	0.1999***	0.3391***
		(0.03)	(0.03)	(0.04)	(0.05)
Log of population density		−0.5809***	0.0148	−0.6129***	−0.3226**
		(0.09)	(0.02)	(0.09)	(0.11)
Political stability		0.1332***	0.1993***	0.1227***	0.1356***
		(0.02)	(0.02)	(0.02)	(0.02)
Level of democracy		−0.0024	−0.0002	−0.0028	−0.0039
		(0.01)	(0.01)	(0.01)	(0.01)
Economic freedom index		0.0041**	0.0073***	0.0048***	0.0041**
		(0.00)	(0.00)	(0.00)	(0.00)
Political corruption		−0.2874**	−0.7386***	−0.2772**	−0.3154**
		(0.10)	(0.09)	(0.10)	(0.10)
Constant	0.3362***	0.7713*	−1.7637***	0.9434*	−1.4726*
	(0.03)	(0.39)	(0.25)	(0.40)	(0.72)
Observation	1,255	1,049	1,049	1,038	1,049
Number of country	117	117	117	117	117
Country-effect	Yes	Yes	Yes	Yes	Yes
Year-effect	No	No	No	No	Yes
Hausman test based on Model 3		139.27***	–		
R^2	0.019	0.207		0.209	0.237

Notes: Standard errors are in parentheses; *, **, and *** denote significance levels of 5%, 1%, and 0.1%, respectively.

Table 5. The result of regression analysis of countries with various democracy levels.

Level of democracy	Low	High	All
Variables	Model 1	Model 2	Model 3
The log of patent grants	0.0216	0.0444**	
	(0.01)	(0.01)	
Interaction of the log of patent grant and Level of democracy			0.0358**
			(0.01)
The sum of exports and imports of goods and services	−0.0001	−0.0019***	−0.0001
	(0.00)	(0.00)	(0.00)
Log of GDP per capita	0.1788***	0.2953***	0.3703***
	(0.04)	(0.06)	(0.05)
Log of population density	−0.2619*	−1.0568***	−0.2815*
	(0.12)	(0.13)	(0.11)
Political stability	0.1177***	0.1598***	0.1269***
	(0.03)	(0.03)	(0.02)
Economic freedom index	0.0066**	0.0028	0.0039**
	(0.00)	(0.00)	(0.00)
Political corruption	−0.3816**	0.0505	−0.2886**
	(0.12)	(0.17)	(0.10)
Constant	−0.8287	2.1942***	−1.9336**
	(0.52)	(0.60)	(0.71)
Observations	376	673	1,049.0
Number of country	58	59	117
Country-effect	Yes	Yes	Yes
Year-effect	No	No	Yes
Adjusted R^2	0.133	0.154	0.131

Notes: Standard errors are in parentheses; *, **, and *** denote significance levels of 5%, 1%, and 0.1%, respectively.

further monitor and censor citizens' expression in authoritarian countries (Chadwick and Howard 2010). But in democratic countries, it will be an effective communication bridge between government and citizens.

Figure A3 in the Online Appendix shows the distribution of each country's democratic level. It is observed that, in 117 countries, the level of democracy is characterized by minor bimodal distribution. According to the median level of comprehensive democracy (7.5044) in 117 countries from 1995 to 2014, the authors divided the national samples of this article into a highly-democratic group and a less-democratic group. Furthermore, this article investigates whether technological innovation in countries with different democratic systems will generate varied effects or not.

Table 5 shows the results of regression analysis of highly-democratic countries and less-democratic counties, respectively. Although technological innovation still has positive effects on GE in different sample groups, there are remarkable differences in the coefficients among countries with different levels of democracy. For instance, the impact of technological innovation on GE in less-democratic countries is only a third of that in highly-democratic ones. This finding suggests that the democratization system can indirectly affect public sector performance through technological innovation. Thus Hypothesis 3 can be proved. Meanwhile, it is also found that the impact of variables such as political stability, political freedom, and political corruption in less-democratic countries is considerably higher than that in the highly-democratic countries. In other words, less-democratic countries are more sensitive to this kind of variables.

5. Robustness test

To further validate the stability and reliability of the analysis results above, the authors made a robust test of the FE model, which was done in three parts: First, we added more controlled variables (Model 2 in Table 6) to see whether it brings significant changes to the results. Second, in consideration of the influence from data completion and balance, the authors compared the differences of regression analysis on initial data and selected data (Model 4 in Table 6). Third, the method of IV was used.

Furthermore, Model 3 applies the method of IV based on the FE model to solve the endogeneity problem. The Stata command of 'dmexogxt' calculates a test of exogeneity for a FE model with IVs. And the null hypothesis is that an OLS estimator of the same equation would yield consistent estimates comparing with the FE model with IVs, which means any endogeneity among the regressors would not have deleterious effects on OLS estimate. Davidson and MacKinnon (1995) discussed that the test may be applied to a subset of the endogenous variables, treating those not specified as endogenous. As shown in Model 3, the Davidson–MacKinnon test of exogeneity is significant, thus denying the null hypothesis. So the IV-FE model can validly solve the endogenous problem of the least-squares estimator of the same equation, such as FE and generalized method of moments (GMM) models. The authors then conducted Sargan–Hansen over-identification test on the IV-FE model. What's more, the non-significant statistics means those two IVs are over-identified. The authors then accepted the null hypothesis that the excluded instruments are valid instruments, that is, uncorrelated with the error term and correctly excluded from the estimated equation. Meanwhile, the innovation in different models still has consistently and significantly positive influences on GE. This further validates Hypothesis 1.

In a stochastic model based on panel data, endogeneity broadly refers to situations in which an explanatory variable is correlated with the error term. Comparing with omitted variables and measurement errors, the endogeneity problem is particularly relevant in the context of time-series analysis of causal processes. GMM estimation was formalized by Hansen (1982) and has become one of the widely used methods of estimation for models in the area of social research. GMM is a nonlinear model with the method of IV. Therefore, it can deal with the endogeneity problem to a greater extent with panel data. This article includes unadjusted data in the regression analysis, and the results (Models 2 and 4) in Table 6 show that technological innovation has a remarkable impact on GE, which is consistent with the previous results of Model 1. Model 5 is the result of GMM and demonstrates that the relationship of technological innovation and GE tested above is also robust even when the endogeneity problem is considered.

6. Conclusion

Based on the data acquired from the political sphere, such as the US NBER patent data, the World Bank social–economic data, and Transparency International data, this article discussed the impacts of technological innovation on GE. The authors' analysis results are demonstrated as follows. First, technological innovation, indeed, prominently stimulates the upgrade of GE. And along with the rapid improvement in science and technology, GE improves synchronously at the first stage. Second, the advancement of GE, which is closely linked to technological innovation, is not simply presented in a linear relationship. Instead, the constantly changing trend turns out an inverted U-shaped curve. Lastly, the impacts of technological innovation on GE vary greatly in different contexts of political systems. For instance, technological innovation could play a preferable role in democratic states, in which GE gains significant promotions, whereas in less-democratic countries, technological innovation could not give full play to its advantages so that the improvement of GE is reflected at a quite lower degree. As a result, this case proves that, despite the fact that in some authoritarian states, an e-government system is broadly applied, the public still has not enjoyed the conveniences of open and transparent official information. It is worth saying that the positive effects brought by technological advancement to the modern government are bound to rely on relevant political systems.

The theoretical inspiration concluded from this article is that, first, since technological innovation has a ceiling effect on GE, other indirect factors need to be further examined when the improvement of GE runs into a bottleneck. Second, certain variables related to the state context, such as the political system and cultural background, have unstable effects on GE.

Nevertheless, this article has the following shortcomings: the data used to measure innovation are based on patents at a nationwide level. These innovations largely feed into the private sector. Sometimes, it is unclear how these technological innovations can improve the government quality. Moreover, most technologies that can improve GE, such as the use of the Internet and computer technologies are worldwide and should not depend on the level of patents produced in a given country. Technology can exist without innovation and innovation can exist without technology. What is unique about innovation and its relationship with government quality remains unsettled. We should address the issue of different levels of technological innovation, global technologies, and their spillover effects at both theoretical and empirical levels. Furthermore,

Table 6. The results of robust test.

Sample	Final data: Model 1	Final data: Model 2	Final data: Model3	Original data: Model 4	Original data: Model 5
Model	FE	FE		FE	GMM
The quality of government regulation			✓		
Internet users (per 100 people)			✓		
The log of patent grants	0.0350***	0.0414***	1.1735*	0.0382***	0.0669***
	(0.01)	(0.01)	(0.47)	(0.01)	(0.02)
The sum of exports and imports of goods and services	−0.0001	−0.0002	−0.0047*	−0.0001	−0.0011
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Log of GDP per capita, PPP	0.3391***	0.3453***	−1.0124	0.3569***	0.1621***
	(0.05)	(0.06)	(0.52)	(0.05)	(0.04)
Log of population density	−0.3226**	−0.2553*	−1.1755**	0.0514	0.0864*
	(0.11)	(0.13)	(0.43)	(0.08)	(0.04)
Political stability	0.1356***	0.1288***	0.4295**	0.1537***	0.1687***
	(0.02)	(0.02)	(0.14)	(0.02)	(0.05)
Level of democracy	−0.0039	0.0018	−0.0810	−0.0099	−0.0135
	(0.01)	(0.01)	(0.04)	(0.01)	(0.02)
Economic freedom index	0.0041**	0.0032*	−0.0025	0.0050***	0.0185***
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Political corruption	−0.3154**	−0.2831**	−1.4243*	−0.3500***	−1.1439***
	(0.10)	(0.11)	(0.61)	(0.10)	(0.22)
Telephone lines		−0.0021			
		(0.00)			
Political imprisonment		−0.0169			
		(0.01)			
Constant	−1.4726*	−1.7476*	12.0553*	−3.1903***	−2.1661***
	(0.72)	(0.83)	(4.87)	(0.61)	(0.43)
Observations	1,049	963	1,035	1,138	1,138
Number of country	117	117	117	131	131
Country-effect	Yes	Yes	Yes	Yes	Yes
Year-effect	Yes	Yes	No	Yes	Yes
Adjusted R^2	0.136	0.111	—	0.123	—
Davidson–MacKinnon test of exogeneity Statistics			103.6347***		
P-value			0.0000		
Test of overidentifying Sargan–Hansen statistics			0.569		
			(0.4508)		

Notes: Standard errors are in parentheses; *, **, and *** denote significance levels of 5%, 1%, and 0.1%, respectively.

regarding the mechanism, it is not sure whether the patents can represent an innovative gain in one specific country. For example, the patent may be registered in one country but the advantages of the patent may take place in any number of different countries. Further refinement of the data will contribute to the study of these problems.

All the controlled variables cited in this article are based on the states of the economy, politics, and society, which dramatically increase the explanatory power of the model and the integrity of the control variables. However, due to the limitation of missing data and difficulties in data collection, some theoretically significant variables, such as the expenditures of the e-government and administrative management, were not considered in this model. Moreover, additional studies are expected to focus on the following aspects. The first is the diverse impacts of technological innovation on the promotion of GE in various regions (i.e. at different economic development levels). The second is to explore in depth the development pattern of global GE in a given time cycle. The third is to focus on the core factors that restrict or improve GE. In addition, we should further explore the influence of different types of innovation, such as production and process innovation or basic and applied innovation. And the differences among these innovation types, not distinguished in this article, will be investigated in the future with the constant upgradation of data quality.

Notes

1. The twenty-seven frequently used variables include demographic characteristics and the socioeconomical status of officials, education, infrastructure, historical culture, labor market, political party and election, public economy, and welfare based on the QOG basic data set (see http://www.qog.pol.gu.se for detail).

Supplementary data

Supplementary data is available at *Science and Public Policy Journal* online.

Additional research data (code and raw data) supporting this publication are available from the Harvard Dataverse, https://doi.org/10.7910/DVN/E0LSH2.

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