

GEOPOLITICS OF TECHNOLOGY: A NEW BATTLEGROUND?

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Abstract. This study aims to consider the causality between global geopolitical risk (GPR) and technology (TEC) using the rolling window approach. The results reveal that GPR has a significant impact on TEC across different sub-samples. It points out that GPR increases TEC and both are highly integrated and the geopolitical constraints are pivotal to TEC development. On the other hand, TEC leads GPR due to competition between countries for geopolitical dominance and security. The results back the Becker Model, which reveals that divergence of interests between countries drive TEC competition and systematically associated with GPR in a country. The international community should create a mechanism that supports interoperability and the states should pay attention to TECs that are critical to economic and strategic interests in the long run. Moreover, the states could enhance cooperation with the private sector which is an important determinant.

Keywords: technology, geopolitical risk, innovation, rolling window.

JEL Classification: C1, F5, O3, O31.

Introduction

We undertake this study with the primary purpose to recognize the relationship between geopolitical risk (GPR) and technology (TEC). GPR is seen in the political, economic and military domain (Khan et al., 2020a) which may increase a country's demands to develop TEC (Wrigley, 1978). TEC is an important feature of globalization, competitiveness and rate of development which is great challenge for countries. It acts as an important tool to overcome constraint and influence politics, military activities, deterrence, warfighting and peacemaking (Mallik, 2004; Diniz, 2019). Undoubtedly, TEC improves the living standards, however, it affects the conduct of states and war. TEC is absolutely the key enabler of modern statecraft and leaves no aspect untouched, and the natural law of the modern world to secure

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a nation is to secure networks. Thus, we look for TEC impact if implemented how nations behave and change the geopolitical status quo (Mialhe, 2018). GPR is equally responsible for TEC development, which is employed to restore its geography and maintain leverage in the international system. This nexus between GPR and TEC will be more noticeable and face new challenges and become a battleground of future geopolitics (Rühlig et al., 2019). Thus, the world faces a “clash of automation” instead of a “clash of civilization” and makes the discussion important.

GPR is once related to physical disruption in a volatile region with explicit impact (Khan et al., 2020b). It turns into a new form that becomes more complex, unpredictable and dominated by TEC. GPR operates on multiple levels ranging from macroeconomics to state terrorism, Internet control, and the state’s competition for technological superiority (Su et al., 2019). However, countries with conflicting motives use TEC to their advantage and no longer leaving it a neutral ground. This has made TEC and GPR more intertwined than ever before, and are using TEC to exert power and influence to shape geopolitics (Wu, 2020). Historically, great powers have established TEC and restore their sovereignty, which changes the world (Fritsch, 2011). It is a double-edged sword that redefines strategic competition and intensifies its expressions. Resources may be the driving force behind geopolitical conflicts (Su et al., 2020) and certain TEC stimulates the non-regionalization of resources and results in GPR. Similarly, a country is dictated by geopolitical constraints and national strategy to develop TEC which overcomes disturbance and secures the sovereignty (Fritsch, 2011). The decline in defence spending (Khan et al., 2020c) increases reliance on TEC to compensate for their lack of smaller militaries. However, different approaches to TEC development threaten to divide the world and shape the contours of the geopolitical rivalry, contributing to TEC competition.

After the cold war, nuclear technology development is the key aspects of GPR. The conflicts of the weapon of mass destruction getting attention and several countries are striving to get nuclear technology to balance regional power and hegemony (Binnendijk et al., 1999; Su et al., 2021a). Emerging economies show a rising trend of military modernization and communication technology is growing, which can make the relationship between countries more complicated (Shaw, 2005; Tao et al., 2021a). The war on terror enhances the role of TEC due to easy availability at low cost which can facilitate and counter-terrorism (Solon, 2018). However, GPR remains at the lowest level in the post-financial crisis period while TEC evidence a promising trend. Most high-tech developments such as very large-scale integration techniques in the past few decades have been driven by security requirement to maintain TEC superiority (Dahlman, 2007). The non-state actors’ phenomenon uses TEC for their malicious activities and challenges the dominant countries (Wade, 2019). Social media has become a powerful force for political and cultural change which is capable to influence global geopolitics. The misinformation spread on social media appears to interfere in internal matters and contributes to the social uprising in the various countries which constantly keep GPR up. TEC development continues and the Fourth Industrial Revolution, which is TEC interplay across the physical, digital and biological fields, is captivating the policymakers, investors and researchers (Chin, 2019; Tao et al., 2021b; Zhang et al., 2020). This wave of innovation in various sectors such as renewable energy, biotechnology aerospace, materials

technology and nanotechnology are deepening the political, economic and military spheres which have disruptive implications and affecting security perceptions. The controversy between the Sino-U.S. over the development of the fifth-generation (5G) network is considered a security threat that leads to GPR. As control over data becomes more important, the manipulation of the 5G technology has greater potential to affect the global economy. The global political dynamic has altered because of TEC and predicts that rapid advancement will change the way nations interact and the start of the “technology cold war” (Chin, 2019).

The research contributes in several forms. First, the study analyzes the influence of GPR on TEC and vice versa and the finding proves that both are highly integrated due to competition between countries for geopolitical dominance and security. In the past few decades, TEC develops from radio, television, and conventional weapons to nuclear, renewable energies, aerospace, biotechnology, nanotechnology, Internet and social media which may be intimately linked to geopolitical conflicts. Second, the results demonstrate the consequences of TEC development because it replaces the conventional approach of war with less risk and makes it risk-free with high accuracy at long range. The real-time information collection enables to detection of a potential threat while the non-state actors and rogue states use it for propaganda. The result suggests TEC facilitates extremism to communicate resentments which translate into instability and unrests (Naughton, 2016). Last, it shows the underlying macro effects in the relationship between GPR and TEC in the sub-samples. It suggests that countries compete to adopt new TECs, which may cause rivalry and countries are struggling to compete. Thus, the study inspects the causality, and the outcome suggests GPR has a significant impact on TEC positively and negatively in several sub-samples. On the other hand, TEC causes GPR positively in sub-samples. The results support the Becker Model, which highlights a close relationship between GPR and TEC. The international community must create a mechanism that supports interoperability. Similarly, the competing countries should extend cooperation in the security and economic domains to handle the GPR consequences of emerging TECs. They should pay concentration to these technologies, which are critical to economic and strategic interests in the long run. The states must enhance cooperation with the private sectors which is an increasingly important determinant.

We prepare the study in seven sections. The literature review is explained in Section 1 which is followed by the Becker Model. The methodology is outlined in Section 3. The data is defined in Section 4, followed by the result section. The last section concludes the study, presents the policy implication and future research direction.

1. Literature review

The study of Ball (1985) establishes that TEC has enhanced GPR importance and illustrates a dynamic relationship among technology, geography and national power. Similarly, Smith (1994) examines TEC advancement impact on historical issues and the finding suggests that TEC is a mean of exerting power in solving strategic problems. Herrera (2003) reveals that TEC is subjected to political contestation and changes in the international system. Dahlman (2007) explains that GPR is a significant component of TEC development, access to new technologies, their expansion may become a driving force for GPR. Fritsch (2011) concludes that

TEC is effective contributor in the structure of the global system and is highly integrated into global political affairs and the major factor of economics and politics. Nasca (2017) shows that TEC development presents a powerful military force and has changed the U.S. relationship with other countries. Bonciu (2017) shows that the future race between geopolitics and TEC outcomes has specific challenges, which is the race between the implications of their outcomes. Fritsch (2017) concludes that GPR shape TEC evolution and act as a crucial element altering the interaction between countries. Mialhe (2018) shows that TEC is rapidly developing and becoming a tool of geopolitical power. Some countries such as the U. S. and China dominate the market and the digital empire has become the battlefield. Flint and Xiaotong (2019) examine the foreign policy changes in the context of GPR. The result indicates that country that most effectively controls artificial intelligence, computer chip technologies and new apps has a dominating role in the international political system. Diniz (2019) finds that the science and technology race has accelerated due to ongoing crises and geopolitical competition. Center and Bates (2020) show that growing geopolitical is the outcome of TEC competition which is one of the most important and complicated challenges for geostrategic competition. Wang et al. (2021) find that GPR and technology security has a significant relationship. Moreover, GPR threatens security and explore time-varying association. Qin et al. (2021) show that uncertainty has both positive and negative impacts on financial technology.

The previous literature shows studies that explain TEC impact on GPR. Hulsman and Liedtke (2019) examine the correlation between GPR and TEC and find that escalation increase TEC development. Rühlig et al. (2019) find TEC has turned in to geopolitical tension between the world-leading powers and become a strategic battleground to future geopolitics. Triolo (2019) shows that the Sino-U.S. long term association is locked around advanced TEC and the competition between the two countries results in the decoupling of technology. Chin (2019) finds that development in defence TEC exerts a significant influence on the conflicts, which results in new strategic forms and a power transition within the states. Rahman (2020) shows that TEC provides a powerful force to protect national interests and pursues a geopolitical strategy and leading factor of GPR. Tekir (2020) confirms that TEC has changed the interaction between countries and the new geopolitical competition takes place on international networks, not on fixed territorial units. Wu (2020) concludes that the fourth industrial revolution has motivated Sino-U.S. to compete for the advancement of TEC, which has increased GPR. The previous literature focuses on the one dimension that TEC has enhanced the geopolitical tension and avoids the role of GPR in technological development. However, GPR is equally responsible for technological innovation as powerful nations develop greater TEC, which is used for dominance in the international political system. Similarly, in most of these studies, the correlation between GPR and TEC is qualitative than quantitative. Therefore, this paper explains the association between and TEC and GPR. TEC development may cause rivalry and countries are struggling to compete which may be linked to geopolitical conflicts (Naughton, 2016). Moreover, we consider the time-varying characteristics to avoid inappropriateness. We use the rolling window method to inspect the connection between GPR and TEC, which has the benefit of identifying structural changes in the sub-samples (Umar et al., 2021).

2. Becker model

Morgenthau (1978) points out that “The fate of nations and civilizations usually depends on differences in war technology that provokes conflicts”. Thus, this study uses Becker’s (1968) model to describe the association between GPR and TEC. It assumes a country considers whether to invest in the TEC sector to enhance its geopolitical strategy denoted by α or in the labour market $(1-\alpha)$. TEC is represented by λ in a country and $\lambda = 0$ shows no type of TEC, which implies it has no divergence with a neighbour (Mahmood & Jetter, 2020). However, the conflicting motives of the countries result in the TEC development to follow their hegemonic policies. Geopolitical constraints and political strategy dictate a country towards the development and attainment of TEC that provides an advantage in war. The development of television, radio and information technology means an increase in λ (Mahmood & Jetter, 2020). Similarly, it describes that TEC brings rapid changes in countries and plays a deciding role in international political relations and strategic alliances.

The maximization function μ of the country comprises of expected return from TEC and GPR.

$$\mu = F(\alpha, \lambda), \quad (1)$$

where λ denote TEC development and α represents geopolitical risk.

Therefore, the production function for GPR is supposed to fulfil the Inada conditions are constituted as follow:

$$F(0, 1) = \frac{\partial F}{\partial i} > 0, \lim_{i \rightarrow 0} \frac{\partial F}{\partial i} = \infty, \lim_{i \rightarrow 0} \frac{\partial F}{\partial i} = 0, \forall i \in \{\alpha, \lambda\}. \quad (2)$$

The higher GPR or the competing interest of countries results in greater investment in TEC. Also, TEC competition may cause conflicts which can have significant consequences for the global political system. We assume that TEC development is probably related to linearity with GRP, which is illustrated as follows:

$$\alpha = \alpha(\lambda), \frac{\partial \alpha}{\partial \lambda} > 0. \quad (3)$$

The profit function of the representative agent can be written as follows:

$$\mu(\alpha) = [1 - p(\lambda)] \times F(\alpha, \lambda) + (1 - \alpha)w. \quad (4)$$

We can obtain the maximizing function from Eq. (3) into a simple form. It clarifies a country’s choice to develop the TEC effect regarding GPR. We can estimate this as follows:

$$\mu(\alpha) = (1 - \lambda)(\alpha\lambda)^\beta + (1 - \alpha)w. \quad (5)$$

Thus, a country invests to develop TEC and maximize μ while it illustrates an equilibrium condition as below:

$$\alpha = \left[\frac{\beta\lambda^\beta(1-\lambda)}{w} \right]^{1/(1-\beta)}. \quad (6)$$

It is revealed that divergence of interests between countries drive TEC competition and systematically associated with GPR in a country. TEC is regarded as a resource and new driving force for geopolitical leverage. The finding shows that GPR increases TEC and both are highly integrated and the geopolitical constraints are pivotal to TEC development. TEC leads GPR due to competition between countries for geopolitical dominance and security.

3. Methodology

3.1. Bootstrap full-sample causality test

The time series does not hold standard asymptotic distribution due to the absence of stationarity. The lack of those characteristics makes the vector auto-regression (VAR) estimation unsuitable (Sims et al., 1990; Su et al., 2021b). Thus, Toda and Yamamoto (1995) propose the Wald test to overcome this issue and estimate the asymptotic distribution. Shukur and Mantalos (2000) correct the size and power characteristics of the small and medium-size improved Wald by the Monte Carlo simulation. A residual-based bootstrap (RB) process is employed to resolve the size and simulation power problem. Hence, the present study employs a technique to assess the causality between GPR and TEC. The RB-based likelihood ratio (LR) test is as follows:

$$q_t = \omega_0 + \omega_1 q_{t-1} + \dots + \omega_p q_{t-p} + \varepsilon_t, \quad t = 1, 2, \dots, T, \tag{7}$$

where $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t})'$ means the white noise procedure with zero mean. We choose the lag length based on the Schwarz information criterion (SIC). Eq. (7) is divided into two sub-vectors:

$$\begin{bmatrix} GPR_t \\ TEC_t \end{bmatrix} = \begin{bmatrix} \omega_{10} \\ \omega_{20} \end{bmatrix} + \begin{bmatrix} \omega_{11}(L) & \omega_{12}(L) \\ \omega_{21}(L) & \omega_{22}(L) \end{bmatrix} \begin{bmatrix} GPR_t \\ TEC_t \\ DE_t \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}, \tag{8}$$

where $\omega_{ij}(L) = \sum_{k=1}^{p+1} \omega_{ij,k} L^k$, $i, j = 1, 2$ and L is the lag operator, defined as $L^k q_t = q_{t-k}$. Eq. (7) tests the impact of GPR on TEC and vice versa. In the past decades, TEC has is driven by security requirements to maintain strategic superiority, peace, sovereignty and national interest. Thus, defence expenditure (DE) is used as a control variable between GPR and TEC. Higher DE can stimulate the development of TEC, which is reflected in geopolitical competition (Rahman, 2020).

3.2. Parameter stability test

There is a consensus that the VAR model parameter in the entire sample does not change. However, Balcilar et al. (2010) show that structural changes can lead to unstable parameters and unsuitable outcomes. As per Granger (1969) various researches have shown that parameter uncertainty is a complication. This question is tested by employing parameter stability tests in the short term. The short term parameter constancy is examined by *Sup-F*, *Mean-F*, and *Exp-F* tests which are suggested by Andrew and Ploberger (1994). Similarly, Nyblom (1989) and Hanson (2002) suggest the L_c test to assess the complete parameter constancy in the VAR system. It depends on the LR statistics to probe the stability of the parameter, allowing the structural breaks (Sun et al., 2021). Moreover, critical and p -values are computed through the parametric bootstrap approach.

3.3. Sub-sample rolling window causality test

To overcome the structural changes and examine the causality in the full sample is achieved via the rolling window approach. Pre-testing is the most suitable for a situation where the

whole sample is nonstationary and shows unpredictability across sub-samples. A stationary rolling window with l full-size observation is changed into the form of a T- l sample $\tau l + 1, \tau l, \dots, T$. The RB-based revised LR method is employed to estimate the sub-samples causality. The time-varying characteristics and extent of the causal link between GPR and TEC are determined from the bootstrap p -values of the identified LR-statistics rolling by T- l sub-samples. The result from GPR to TEC is equal the formula proves to the average of all bootstrap estimates $N_b^{-1} \sum_{k=1}^p \omega_{21,k}^*$, where N_b shows the number of bootstrap repetitions. Also, the causality of TEC on GPR is expressed by the following formula $N_b^{-1} \sum_{k=1}^p \omega_{12,k}^*$. Eq. (7) is the basis to evaluate the values of $\omega_{21,k}^*$ and $\omega_{12,k}^*$ in the VAR model. The precision of parameter approximation and the representativeness of the model during the sub-sampling time has different objectives.

4. Data

The study considers monthly data from 1996:01 to 2020:12 to analyze the causality between global GPR and TEC. The geopolitical landscape changes from 1996 onward in the Cold War period, which leads to a reduction in global defence expenditures on research and development while GPR remains low (Chin, 2019). On the other hand, a transition toward TEC development has witnessed an extraordinary investment that outlines the future geopolitical battleground among countries. Moreover, TEC assumes unprecedented importance and reduces human role and global R&D spending on TEC increase in the 2000s, especially in internet-based technologies (Brzoska, 2006). Broadband usage has surged worldwide, Google and social networks have become popular. Similarly, the global positioning system (GPS) is increasingly popular in space TEC for tracking, which is driven by GPR. During the period, TECs affect agriculture, such as gene editing, energy consumption, battery storage and renewable technologies which have intensified the competition and reflect in geopolitical conflicts. Moreover, industry and manufacturing are changing through robotics and automation. Social media is a crucial factor influencing the economy and global geopolitics. GPR events directly or indirectly related to TEC development and lead to competition between states. Thus, TEC is the new battleground that has no boundaries and uncontrollable ramifications (Rühlig et al., 2019).

Caldara and Iacoviello (2018) estimate the GPR index, which is the outcomes of the war, terrorist attacks and interstate conflicts that interrupt the routine of national strategies and international dealings. We gather the data for GPR from the Matteo Iacoviello website¹. The global Research and development expenditures are used to represent TEC and are retrieved from the World Development Indicators (WDI) (Suleman et al., 2020). It includes the capital and current expenditures of commercial organizations, government and education institutions. DE is the global spending on defence that can stimulate the development of TEC, which is reflected in geopolitical competition and obtained from the World Bank database (Rahman, 2020). The global system is shifting driven by TEC which is partly contributed by

¹ <https://www.matteoiacoviello.com/gpr.htm#data>

the defence and security requirements of a county. The camera is invented by the National Reconnaissance Office and the cell phone is made by the U.S. Army as a mode of communication. Similarly, GPS is designed for missiles and the microchip is invented for submarine ballistic missiles and the internet is developed by Defence Advanced Research Projects (Friedman, 2019). Therefore, the powerful countries develop TEC motivated by the defence purpose which is vulnerable to GPR.

Figure 1 highlights that the Iraq disarmament pushes GPR in 1998, mainly stem from the development of a weapon of mass destruction and missile. There is a huge development in the nuclear field when Pakistan and India have obtained nuclear technology, resulting in high GPR in the region (Mallik, 2004). The Dot-com bubble crisis results in a massive sell-off of stocks, as demand disappears, leading to huge uncertainty in the information technology industry. TEC is mainly dominated in the 2000s by the internet and the information technology industry is booming, which can influence global geopolitics. Europe remains volatile during 2004–2005, due to various terrorist attacks which results in the rising GPR (Caldara & Iacoviello, 2018). However, TEC’s development is attributed to the launch of Facebook and mobile phone innovation (Gill et al., 2015) which is one of the facilitating factors in terrorist attacks. However, the financial crisis in 2008 has squeezed the global economy, but information technology is growing because data storage needs to keep rising (Lister & Cruickshank, 2013). The phenomenon of non-state actors fully takes advantage of social media in the post-financial crisis and uses it as a destructive weapon (Singer & Brooking, 2018). We observe social media reflection in the Arab spring, connecting people which results in the social unrest in the Middle East (Alhindi et al., 2012). TEC helps to improve policing capabilities, disseminate and collect information, which may prevent terrorist attacks (Naughton, 2016).

The Fourth Industrial Revolution, characterized by artificial intelligence, has prompted countries to actively compete to develop and use these technologies which result in the strained relation among countries (Wu, 2020). It coincides with the Sino-U.S. conflicts in 2018 due to TEC competition, which translates into a higher GPR (Tellis, 2020). TEC helps

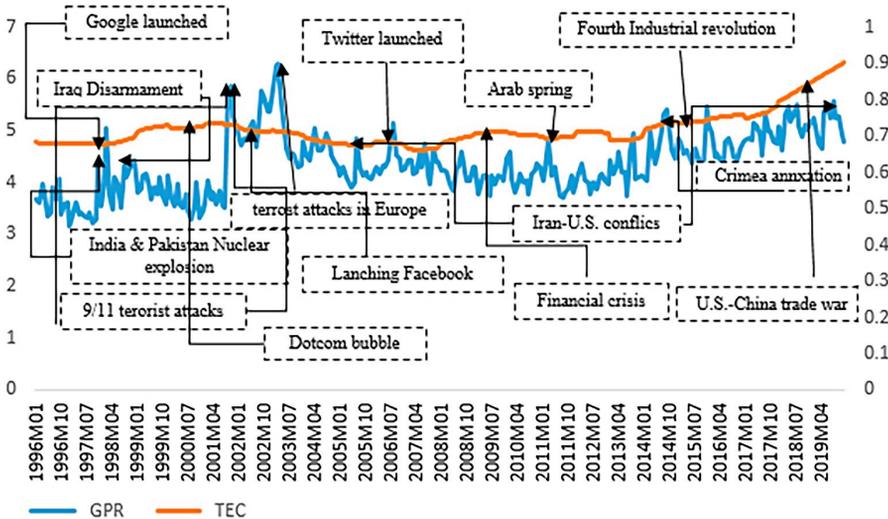


Figure 1. Trends of GPR and TEC

in monitoring, surveillance, detection and prevention of coronavirus (COVID-19), countries having the better technological infrastructure to cope with pandemics. The summary statistics of GPR, TEC and DE are illustrated in Table 1. It shows that both GPR and TEC are skewed to right, suggesting greater changes over the period. However, DE is skewed to the left with a kurtosis value less than 3. Similarly, the kurtosis of GPR and TEC are leptokurtic distribution because their values are greater than 3. GPR, TEC and DE are non-normally distributed as per the Jarque-Bera test. It is confirmed that the conventional Granger test is not suitable to evaluate the nexus between GPR and TEC. Thus, we employ the rolling window process to analyze the mutual relationship.

Table 1. Descriptive information

	Mean	Std. Dev.	Skewness	Kurtosis	J-B
GPR	95.050	68.695	2.740	14.632	1984.073***
TEC	2.053	0.102	2.044	7.355	428.284***
DE	13.998	0.376	-0.320	1.329	36.069***

Note: GPR shows geopolitical risk, TEC represents technology and DE indicates defense expenditures. *** denotes significance at 1% level, respectively.

5. Empirical results

The stationarity is examined by employing the different unit root tests and results are illustrated in Table 2. The Augmented Dickey-Fuller (1981) test, Phillips-Perron (1988) test, and Kwiatkowski-Phillips-Schmidt-Shin (1992) test show that GPR, TEC and DE are stationarity at the first difference level. The stationarity justifies to construct VAR model for the Granger causality.

The full sample Granger causality between GPR and TEC is examined and results are exhibited in Table 3. The results confirm that GPR is explaining TEC by rejecting the null at a 1% significance level. It implies that GPR is an important component of TEC development, access to new technologies, their expansion and regulations may become a driving force for GPR. Thus, geopolitical phenomena shape TEC evolution and act as a crucial element to alter the interaction between countries (Dahlman, 2007; Chin, 2019; Su et al., 2021c).

Table 2. Unit root test

	ADF	PP	KPSS
GPR	-1.604 [2]	-1.767[2]	0.791[2]***
TEC	-1.562[4]	-1.450[4]	0.950[5]***
DE	-1.027[4]	-0.615[4]	0.978[4]***
Δ GPR	-4.093[3]***	-4.089[2]***	0.063[3]
Δ TEC	-3.756[5]***	-3.111[4]***	0.056[4]
Δ DE	-5.004[2]***	-5.882[2]***	0.089[4]

Note: *** indicates the significance level at 1%. The figures in parenthesis express lag length according to the SIC selection.

Table 3. The full sample Granger causality test

Test	H ₀ : GPR does not Granger cause TEC		H ₀ : TEC does not Granger cause GPR	
	Statistics	p-values	Statistics	p-values
Bootstrap LR test	8.837***	0.000	0.454	0.820

Note: *** denotes significance at 1% level.

The full sample includes single causality and no structural changes (Su et al., 2021d). Our results are not in line with the assumption because the causal link between GPR and TEC experiences structural changes. This makes the short-run parameter instability and results are misappropriated for the analysis. The problem is examined by various parameter stability tests such as *Sup-F*, *Mean-F*, and *Exp-F* to scrutinize the short-run instability in the model and Table 4 highlights the results. We reject the underlying hypothesis for both GPR and TEC respectively, which suggests that series have short-run uncertainty. Likewise, the *Mean-F* and *Exp-F* are employed to inspect the hypothesis of a sharp shift. We cannot accept the hypothesis which shows that GPR and TEC are evolving. The overall VAR model stability is examined through the *Lc* test to confirm whether the parameter follows a random walk. It investigates the parameter stability against the random walk and results confirm that the full-size VAR model has short-run instability. Thus, it is confirmed that the full sample subject to parameter constancy in the short term because of structural changes and the entire sample is inappropriate.

To overcome the problem of structural change, the Bai and Perron (1998) test is employed to examine the structural breaks in the GPR and TEC. It allows multiple breaks and to determine the variables of the breakpoint. The results are illustrated in Table 5. The finding of the Bai-Perron test confirms three structural breaks for GPR and four breaks for TEC, respectively. The structural breaks of GPR occur in 2001M09, which coincides with the terrorist attacks in the U.S. The next structural break is detected around 2005 which is mainly caused by the terrorist attacks in Europe, which increases GPR. Similarly, a break is observed in GPR in 2014 as a result of the Ukraine crisis and Crimea annexation of Russia in 2014, the Islamic State of Iraq and Syria (ISIS). On the other hand, four structural breaks are observed in TEC. The first break is observed in 1999 due to the end of the Cold War and the launch of the war against terrorism, countries continue their security in the prism of technological progress.

Table 4. The parameter stability test

	GPR Equation		TEC Equation		VAR system	
	Statistics	p-values	Statistics	p-values	Statistics	p-values
<i>Sup-F</i>	38.607***	0.004	24.180*	0.097	62.980***	0.000
<i>Mean-F</i>	10.053**	0.031	14.373*	0.059	21.919*	0.012
<i>Exp-F</i>	15.696**	0.018	9.254*	0.054	26.182***	0.000
<i>Lc</i>					5.084**	0.048

Notes: *, ** and *** represent significance at 10%, 5% and 1%, respectively.

Table 5. Bai-Perron test of L+1 vs. L sequentially determined breaks

Break test	GPR		TEC	
	<i>F</i> -statistic	Critical Value	<i>F</i> -statistic	Critical Value
0 vs. 1	147.589***	8.58	172.189***	8.58
1 vs. 2	14.295***	10.13	54.662***	10.13
2 vs. 3	126.267***	11.14	44.470***	11.14
3 vs. 4			145.667***	11.83
Break date	2001M19 2005M04 2014M07		1999M08 2004M01 2008M09 2016M06	

Note: *** denotes significance at the 1% level.

The next structural break is detected when the TEC shows unprecedented rising trends. Similarly, a structural break occurs during 2008 which coincides with the global financial crisis which has squeezed the global economy and affected TEC. The last structural break is detected in 2016 which coincides with Fourth Industrial Revolution. The 24 month window size has been used in this study that is appropriate for the test results reliability².

We find reliable outcomes between GPR and TEC through the rolling window, taking into account the structural changes. The underlying hypothesis that GPR does not Granger cause TEC is tested and the VAR model estimates the *p*-values obtained by the VAR model. Figure 2 illustrates the results about the causal link of GPR on TEC detects the relationship across several sub-samples; including 1998:02–1999:02; 2004:06–005:02; 2006:01–2006:04; 2009:04–2009:09; 2013:10–2014:02 and 2018:04–2018:08. It shows that GPR has a decisive role in TEC development to overcome internal unrest, prosecute wars, secure borders and maintain hegemony.

Figure 3 highlights the results which confirm the direction of the causality between GPR and TEC. It displays positive relationships between GPR and TEC in a sub-sample of 1998:02–1999:02. During the period between the end of the Cold War and the launch of the war against terrorism, countries continue their security in the prism of technological progress (Chin, 2019; Su et al., 2021e). The weapon of mass destruction technology becomes cheaper and easily available to the rogue³ states with a long-range delivery system and accurate guidance. These states such as Iran, North Korea, Libya, Cuba and Iraq pose a risk to use weapons against their neighbour leads to continuous global instability. North Korea attempts to put a satellite into orbit in August 1998, suggest that it pursues long-range weapons of mass destruction (Binnendijk et al., 1999). The Iraq disarmament in 1998 is an important incident which escalates tension and GPR spikes (Caldara & Iacoviello, 2018). They accuse the country of developing biological, chemical and nuclear weapons and missiles to attack

² We use different rolling window size such as 20-, 28- and 32- months to confirm the robustness of results. The results are similar with 24-months outcomes.

³ The word is coined by the Clinton administration and defines rouge states as outlaw states and choose to stay outside of the family of democracies. It remains a source of contention and strong connection with terrorism and threaten US and its security.

neighbouring countries which keeps GPR rising. Congress allows the U.S. President to take measures to remove the dictatorial government, which is reciprocated by Iraq not cooperating. The United Nations Security Council (UNSC) imposes sanctions against Iraq because of non-compliance with its resolution. Thus, nuclear technology is the key factors to push GPR and culminates in the Iraq war in 2003. The two rival countries Pakistan and India develop nuclear technology to maintain geostrategic dominance and secure territorial integrity which results in the nuclear explosion. This alters the regional security situation and countries are on the brink of war, which leads to higher GPR (Mallik, 2004). India seeks to be a regional and even international power while Pakistan pursuing its security, thus the factor has led both countries to develop nuclear weapons and missiles and the beginning of endless conflicts

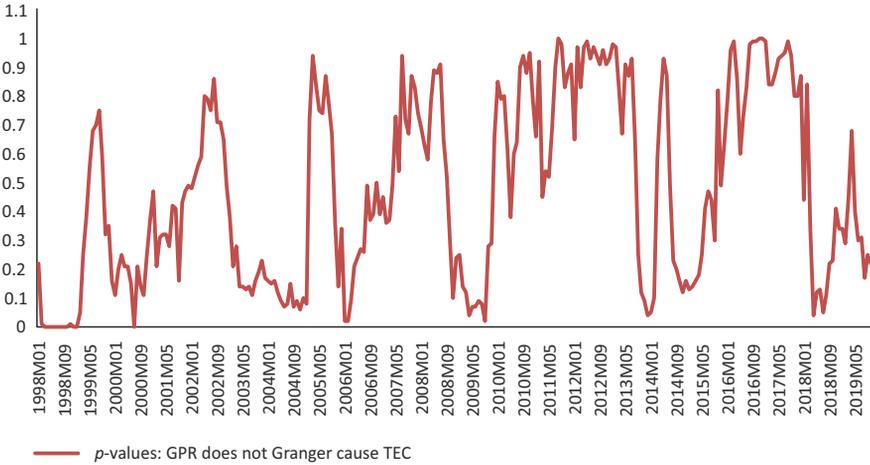


Figure 2. GPR causal impact on TEC

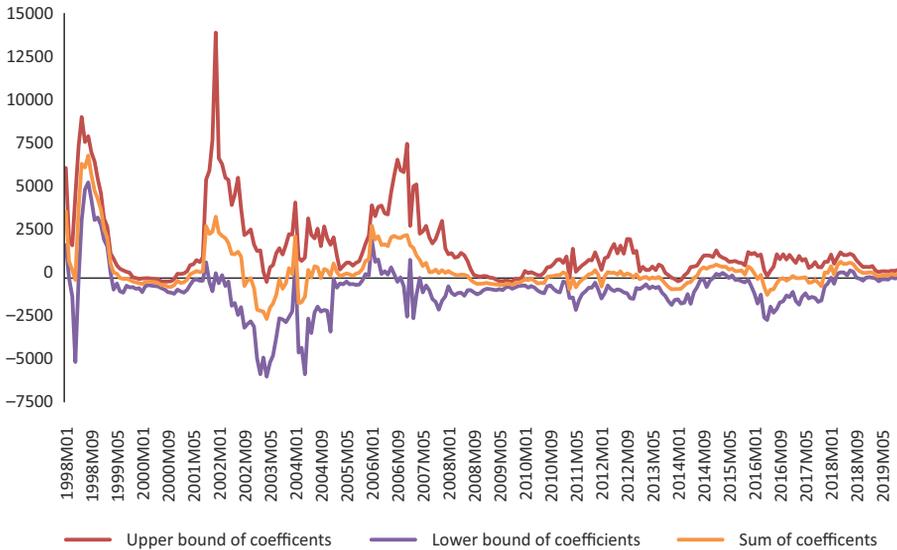


Figure 3. The direction of GPR impact on TEC

(Binnendijk et al., 1999). During the period, the development of the internet and especially Google gives new dimensions to information and communication technologies and has gotten more importance. It has made war “risk-free” and engages with high accuracy at long range without firing weapons (Shaw, 2005). We observe this manifestation in the North Atlantic Treaty Organization (NATO) bombing in 1999 against Serbia (Bobbit, 2007).

We find GPR is causing TEC during 2004:06–2005:02, corresponds with the major terrorist attacks in Europe, which increases GPR (Caldara & Iacoviello, 2018). The period is coinciding with an extraordinary boom in information and communication technology, which is available at low cost, available to weak countries and non-state actors (Solon, 2018). This is one factor that encourages terrorist organizations and their supporters to use the internet for recruitment, funding, propaganda, training, collecting and disseminating information (Gill et al., 2015). The development of social media and communication technology has made terrorism more attractive as a strategy for expressing grievances in the early stages but reduces after further development (Mahmood & Jetter, 2020). GPR is causing TEC in 2006:01–2006:04. Iran voluntarily suspends additional protocols and other non-legally binding inspection procedures in 2006. It continues to enrich uranium, and the UNSC offers Iran to stop the enrichment program. However, Iran rejects the proposal and declares the nuclear program for peaceful purposes. The UN imposes sanctions on Iran, prohibiting countries from transferring nuclear and missile technology and freezing assets. During the period the most important aspect is the war on terror which is expressed in the counter-insurgency and it views TEC as a silver bullet that is proved useful in the situation caused by the human and geography of war (Chamayou, 2015). It replaces capital and labour-intensive tactics of war with less risky methods conducted through satellites, robots and drones. The conventional war against terror is challenged in 2006, which is responded by replacing the latest TEC to compete for counter-insurgency (Chin, 2019). Several countries use the mass media for propaganda to directly demobilize terrorists and form a public opinion against anti-state actors (Wanta & Kalyango Jr., 2007). In the transatlantic aircraft plot; a terrorist attempt to detonate liquid explosive is foiled due to surveillance technology.

There is a negative impact of GPR on TEC in the sub-sample of 2009:04–2009:09. GPR remains at the lowest level during the period, and the world is suffering the financial crisis effects. TEC development boom-bust pendulum moves along with economic growth which is in bad condition due to the financial crisis. However, information technology is constantly developing and innovation turns crises into opportunities. Similarly, during the economic downturn enterprise data storage needs rise which gives impetus to TEC development. Meanwhile, the rise of smartphones, the development of laptops and Twitter shows rapid growth. The political consequences of the micro-blogging trend became clear when Iranians have used social media to organize and publicize protests of a disputed presidential election and grab the world’s attention.

GPR has a negative impact on TEC from 2013:10 to 2014:02. TEC is used by states and non-state actors for their respective purposes. The states apply to predict and control the destructive activities while non-state elements use to follow its heinous agenda and exploit emerging technologies to defy powerful countries. The obvious manifestation is the ISIS and some dissenting countries like Russia have fully exploited social media to weaken the opponents (Wade, 2019). It is claimed by these non-state actors that media can be more power-

ful than bombs (Singer & Brookings, 2018). Similarly, during the period, Ukraine crisis and Crimea annexation of Russia in 2014, challenges European security and one of NATO's major tasks, which uses satellites for surveillance of the Eastern border to deter aggression. This conflict is the catalyst for spending on TEC, especially military technology in Central and North European countries, to assure deterrence for potential hostility. The development of communication technologies has improved the aerial surveillance of terrorists (for example, through spy drones) which helps to collect real-time data for actions (Naughton, 2016). The enormous increase in data storage capability helps to find and track the expected terrorist (Brown & Korff, 2009). The social media revolution contributes to reawaken awareness in the Arab world and plays a pivotal role in communicating with people which results in mass protests in the Middle East and toppling several governments (Alhindi et al., 2012). It is used effectively by protestors in the Syrian civil war, showing the government atrocities to gain international support for the insurgency. Non-state actors invade websites through cyber-attacks to intercept sensitive data and threaten the government. Moreover, the online technology application is used by terrorists to locate and strike long-range weapons (Lee, 2016).

GPR is leading TEC positively during 2018:04–2018:08. This period is characterized by artificial intelligence, big data, 5G, nanotechnology, biotechnology and robotics, prompting countries to compete to develop and use these technologies which result in conflicts (Wu, 2020). Similarly, it coincides with the Sino-U.S. conflict caused by TEC competition. The remarkable economic development has positioned China as a leading player in innovative technologies which can influence dynamics of the power politics. The U.S. accuses theft of technology and intellectual property rights and imposes tariffs on imports while China responds to this equally. It has challenged the pursuit of China's technological dominance and target its industry on the pretext of security concerns (Tellis, 2020; Wu, 2020; Tian et al., 2020). Both countries know that TEC advance is an important cause of national power that cannot be compromised (Wu, 2020). Also, North Korea has conducted a series of missile and nuclear tests, demonstrating that it can launch ballistic missiles outside of its neighbouring areas, and results in GPR (Wade, 2019). The U.S. has imposed sanctions on Russia in 2018 because of the invasion of Ukraine, election interference, malicious cyber activities and the two countries have been at daggers drawn. Likewise, the U.S. has annulled the "Iran nuclear deal" to control nuclear technology development, which can cause a reason for GPR.

Figure 4 illustrates the results about the causal link of TEC on GPR detects the relationship across several sub-samples; including 2000:03–2000:08; 2005:03–2005:09. It shows that TEC may encourage countries to compete and a powerful force to protect national interests and pursue geopolitical dominance (Rahman, 2020). Thus, countries are obsessed with the technological cold war such as the tension between Sino-U.S., which is driven by competition and results in conflicts. It implies that TEC advantage can cause GPR and becomes a future battleground (Rühlig et al., 2019).

The positive relationships between TEC and GPR across the sub-sample comprising 2000:03–2000:08 and 2005:03–2005:09 are shown in Figure 5. TEC is explaining GPR in 2000:03–2000:08. It coincides with the transition period when several countries such as India, China and Russia aim to create a foundation for regional or international power. We observe a rising trend of TEC modernization and development in these countries. Similarly, a shift has

been seen towards the second generation of Intercontinental Ballistic Missile System (ICBMs), developing medium and short-range mobile missiles with global positioning systems and cruise missile system which may cause GPR (Binnendijk et al., 1999). During the period Dot com bubble occurs which is mainly caused by the heavy investment in internet-based stocks. However, as demand declines and restrictions on risky financing exacerbate the economic downturn, the bursting of the internet bubble leads to a massive sell-off of stocks which creates uncertainty in the technology sector. From 2005:03 to 2005:09, TEC is causing GPR positively.

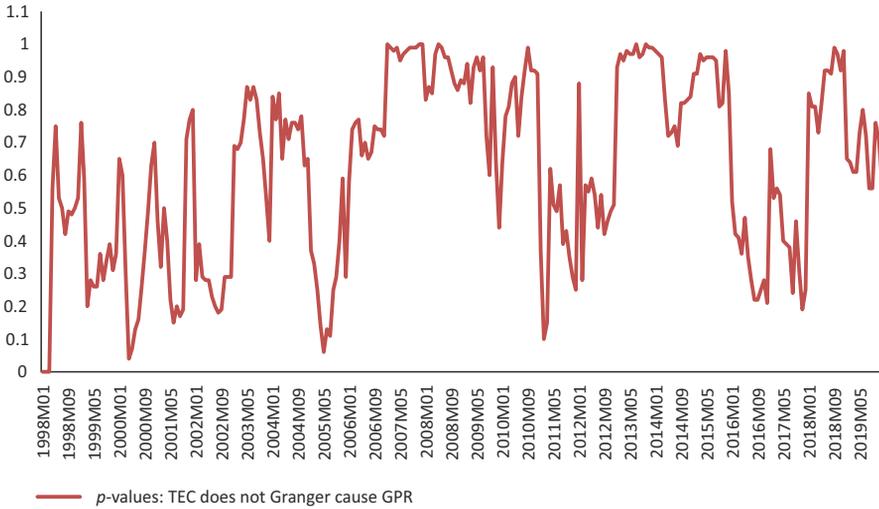


Figure 4. TEC causal impact on GPR

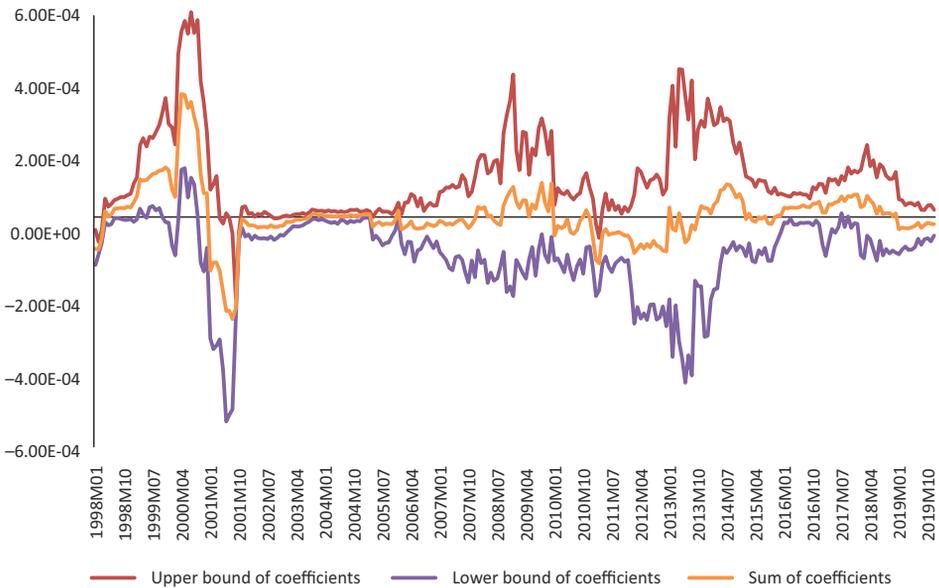


Figure 5. The direction of TEC impact on GPR

This period is described by the continuous progress of TEC, in which social media and smartphone innovation have become more prominent. It can promote a wide range of purposes, such as recruitment, funding, training, gathering and circulating information for terrorist activities. Social media has become a powerful force to stimulate political and cultural change and can influence global geopolitics. Moreover, it is a propaganda tool to spread information and deepen partisanship, sow violence against individuals and religious or ethnic groups, and have played a role in many protests that lead to government changes. The spread of terrorism and fundamentalism worldwide has aggravated the security and vulnerability of modern society. However, TEC progress has also promoted the efficiency of these terrorists and their sponsors (Mallik, 2004).

Table 6 summarizes the relationship between GPR and TEC. It shows the specific subsamples, direction and length of a causal relationship. The causality running from GPR to TEC includes both positive and negative effects. However, the length of positive causality is greater than the negative. It implies that TEC evolution is shaped by geopolitical phenomena and an important factor that alter the geopolitical dynamics. A country’s geopolitical restrictions and national strategy decide which technology to develop. The different TEC development approaches threaten to divide the world and results in GPR, further promoting the securitization of TEC competition. The causal relationship from GPR to TEC coincides with the initial stage of the Internet revolution, for example (1998:02–1999:02); the second stage (2004–2006) and the Fourth Industrial Revolution (2014–2018). The causality running from TEC to GPR is positive and short, mostly coincides with the low GPR period. The results support the Becker Model, which emphasizes a close relationship between geopolitics and technology. The international community must create a mechanism that supports information sharing. They should pay concentration on these technologies, which are critical to economic and strategic interests in the long run.

Table 6. Summary of the relationship between GPR and TEC

Causality	Time period	Direction	Length months
GPR → TEC	1998:02–1999:02	Positive	12
	2004:06–2005:02	Positive	8
	2006:01–2006:04	Positive	4
	2018:04–2018:08	Positive	4
	2009:04–2009:09	Negative	5
	2013:10–2014:02	Negative	5
TEC → GPR	2000:03–2000:08	Positive	5
	2005:03–2005:09	Positive	6

Conclusions

This study inspects the causality between GPR and TEC by the rolling window procedure. The outcome of the full sample displays that TEC is driven by GPR. The rolling window results show a two-way causality between GPR and TEC across various sub-samples. There is both a positive and negative impact running from GPR to TEC. It implies that GPR and TEC are highly integrated into political affairs and geopolitical conflicts increase TEC development. The results are similar to the previous studies of (Smith, 1994; Fritsch, 2011; Bonciu, 2017; Center & Bates, 2020), which explains that GPR is one of the leading factors of TEC development. Similarly, TEC is leading GPR positively, which implies TEC competition results in conflicts and becomes a force to defend national sovereignty and enhance geopolitical dominance. The results are similar to the (Rühlig et al., 2019; Triolo, 2019; Rahman, 2020; Tekir, 2020) which states that TEC development leads to GPR. The results back the Becker Model, which reveals that divergence of interests between countries drive TEC competition and systematically associated with GPR in a country. The international community should create a mechanism that supports interoperability and the states should pay attention to TECs that are critical to economic and strategic interests in the long run. Moreover, the states could enhance cooperation with the private sector which is an important determinant.

The policy implication of the study is explained as follow. First, the finding reveals that TEC development is shaped by geopolitical restrictions and national strategy. The close relationship between GPR and TEC and the global scenario becomes multipolar and no single county has the power to impose its interest. The global system is the aggregate of the economic and political matrix; the TEC race widens fragmentation. Thus, the global community must create a mechanism that supports interoperability. Second, TEC progress constantly confronts human beings with new challenges, which generates threats for global politics. Thus, the competing countries should extend cooperation in the security and economic domains to handle the GPR consequences of emerging TECs. Last, the Fourth Industrial Revolution TEC hastens the redistribution of geopolitical power. Thus, they should pay concentration on these technologies which are critical to economic and strategic interests in the long run. Further, the states must enhance cooperation with the private sector, which is an increasingly important determinant. The research can be extended in the future by considering the geopolitical risks challenges posed by the fourth industrial revolution. It has revolutionized every segment of society by fusion of advances in artificial intelligence and robotics. This innovation can improve human living, development and prosperity. On the other hand, these recent innovations are deepening the political, economic, environmental and military spheres. Thus, this study can examine the geopolitical risks challenges created by the fourth industrial revolution. Similarly, it can analyze the social media relationship with GPR. Social media has become a powerful tool of opinion-making and geopolitical tensions between different countries. Therefore, the contributions of social media in GPR can be an interesting discussion.

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