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ROLE OF GEO-ECONOMICS, GEO-POLITICS AND REGIONAL TRADE AGREEMENTS IN TECHNOLOGY ADOPTION AMONG GLOBAL POWERS: An Econometric Approach

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Abstract

The primary focus of this study is to determine whether global economic relationships, political ties, and regional trade agreements significantly affect technology adoption. The comparison is drawn between two groups: the first includes the superpowers and middle regional powers, and the second consists of minor regional powers. Panel data econometric techniques are applied using the fixed effect model based on 26 countries for econometric analysis. Due to the autocorrelation and heteroskedasticity problems, Driscoll-Kraay standard errors were estimated, which are robust to these issues. The study's empirical results show that a country's geo-economic relationship and geo-political security have positive and significant impacts on the technological adoption of a country, which is valid for both groups. Moreover, disintegrating the data for further analysis shows mixed impacts of regional trade agreements on technology adoption. Due to high intellectual property rights restrictions, regional trade agreements negatively affect super and significant power groups. In contrast, in the case of minor power groups, their impact on technology adoption is positive. These findings reveal that countries should focus on increasing geo-political security and enhancing economic ties with other regional powers to improve technology adoption.

Keywords: Technology Adoption, Security, Geo-economics, Geo-Politics.
JEL Classification: O33, F52, F59.

I. Introduction

In the last few decades, researchers have been paying growing attention to the importance of technology in economic development and how various factors are shaping this technological advancement. Owing to this, a significant focus has shifted towards maximising technology adoption. In this regard, some countries have achieved their desired goals and objectives, while many are still struggling and trying to reach the maximum level. Previously, studies have focused on the implication of regional trade agreements on technology transfer. However, there has been very little focus on the

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role of geo-political and geo-economic factors. The focus of this empirical study is restricted to factors such as geo-economics, geo-politics, and regional trade agreements. Furthermore, the study compares super, middle, and minor powers. Moreover, it focuses on understanding how these factors play a pivotal role and subsequently impact technology adoption levels in these countries.

The advent of the modern world is characterised by rapidly intricate geo-political interactions, continuous technological adoption, and a growing global reliance on technology for expeditious economic growth and innovation. It has made the interplay of geo-economics, geo-politics, and trade agreements the critical determinants of global influence. Geo-economics refers to studying and using economic instruments to achieve international economic objectives. It examines how countries utilise economic tools such as trade policies, investment, and economic sanctions to influence the behavior of other nations and achieve strategic goals. Moreover, it is the economic means of power to achieve strategic objectives, as explained by Scholvin and Wigell (2018).

On the other hand, geo-politics is an understanding of the effects of geography (including human and physical) on international relations and politics. It incorporates the strategic considerations of countries regarding their geographic locations, resources, and boundaries and how these factors influence political decisions and power dynamics on a global scale. In addition to internal technology progress, technology adoption and technological advancement across the border are irrefutably among the most paramount factors in determining economic development. Strategic alliances and the economic imperative of nations worldwide profoundly shape it. Technology adoption can be via indirect technology spillover (which is the transfer of technology indirectly through channels like employee mobility, trade, and multinational firms). It can be through direct trade agreements or adding technology-related provisions, but geo-politics and geo-economics are the determining factors. Moreover, these factors vary across countries due to different economic, political, and geographic dynamics. Countries that have better economic relationships with other countries experience more technological diffusion than countries with less developed economic ties [Eaton and Kortum (2006)].

The indirect spillover of technology is also essential, as Hoppe (2005) explained. It depends upon three factors: the difference between the trading countries, the capacity to adopt technology, and the ability to make technology successful. The Total Productivity Factor (TPF), which measures efficiency and considers all inputs used in the production process, has been used as an indicator to measure this technology spillover pertaining to an increase in production and efficiency. However, it depends on the geo-political relationship among the countries, for example, how much cross-border movement or immigration exists between countries. Furthermore, another way of technology adoption is through RTAs and the inculcation of specific technology transfer-related provisions in the agreements, as explained by Martínez-Zarzoso and Chelala (2021), that RTAs, in some cases, can be used as a tool to increase technology transfer. The

RTAs that resulted in expanding the technology transfer agreements also include specific provisions that regulate such technology transfer. One such example is TRIPS (Agreement on Trade-Related Aspects of Intellectual Property), which must be complied with by the country's members of the WTO in RTA. It further highlights that, although most of the time the impacts of these RTAs are positive, they have adverse effects on exports from developed to developing countries. It is relatively complex for developing countries to comply with these intellectual property rights-related provisions. Ivus (2010) and Delgado (2013) also found that the more substantial patent and intellectual property rights in the trade agreements resultantly increased technology flow, prominently from developed to developing economies. This flow direction is also supported by Kasahara (2004), who examined the applicability of the flying geese paradigm in East Asian economic development. He suggested that industrialisation and economic growth spread from the more advanced economies to less developed countries, resembling the formation of a flying V-shaped pattern.

Another critical factor in this regard is the country's capacity for technology adoption. This capacity depends on various factors, including socio-economic and socio-political ones. Sometimes, the level of technology diffusion is very high among countries, as in the case of regional allies or partner countries. Although the inward flow of technology is very high, the state on the absorption side, due to its poor infrastructure, does not have enough capacity to absorb at the same level as the flow is happening. Poor fiscal conditions, worse economic health, or a low level of education can be a few reasons that restrain the country's technological absorption, despite its good economic relationships and a better geo-political position.

In such cases, an effectively designed and well-implemented technology adoption-oriented policy framework by these countries, with proper management and utilisation of resources, is essential. It can positively and significantly contribute to a country's technological advancement and economic growth. Contrary to this, in the absence of geo-economic relationships, a security framework, and regional ties, the government has started to lag in technology.

Technology is another key driver in a country's economic growth and progress. It plays a pivotal role in economic development. Every country tries to create a tech-driven economy to achieve the desired economic progress. However, there still exists an unequal level of technological advancement among the nations, which is the cause of technological disparity. Some countries have better levels of technology due to their high resource intensity, better economic relationships, and strong security.

On the other hand, countries with a low level of resources, less developed economic relationships, and weak political security face constraints and have failed to achieve a similar level of technological adoption. There is a need to explore how this disparity and economic differences impact technology adoption and restrain the economic growth of a country. It also emphasises understanding differences in the level of technology at the county level and on the geo-economic fronts among various countries. This research focuses on how economic relationships, geo-political security, and international trade agreements contribute to technology adoption. It focuses on determining whether geo-political relationships and regional trade agreements affect technology adoption and to what extent. This study varies from the existing literature as it analyses the impacts of geo-economic relationships on the scale of technological adoption in countries belonging to various power groups. The group of countries is based on their role in the region and their position in influencing other states, rather than the distribution based on the income group. This provides a whole new dimension to the study.

This study proceeds as follows: Section II presents the literature review, Section III discusses the theoretical framework of the study, Section IV details the model specifications and estimations, Section V discusses the estimated results, and finally, Section VI offers the conclusion and policy recommendations.

II. Literature Review

The connection between geo-economics, geo-politics, trade agreements, and technology transfer represents a complex interaction that shapes the global economic outlook. This literature review intends to analyse and critically evaluate existing literature and scholarly work on this topic. It also presents a comprehensive insight into different dynamics that impact and influence the harmonisation of technology transfer worldwide. Geo-economics primarily understands how a country's geographic location, resources, and interests influence its economic strategies and interactions with other nations. All these factors are pivotal in the technological flow pipeline with other countries. Klement (2021) has discussed that geo-economics is the key determinant in deciding the country's investment, research, and development. At the same time, studies by Sachs and Warner (1995) and Auty (2001) emphasise the role of resource abundance and dependency in shaping a nation's approach to technology transfer. Although geography is a permanent obstacle in the rise and progression of economies, the most critical determinants in today's geo-economic rivalry are not the resources but rather access to data and innovation [Csurgai (2017)].

Abundant resource-rich countries may develop and eventually transfer technology to diversify their economies. In contrast, resource-poor countries may seek technology and engage in technology adoption to enhance resource exploitation. The geographical position of a country decides many factors, especially regarding its trade policies and relationships with other countries. The same goes for the transfer of technology, as Keller (2004) argues that geography is the direct determinant of technological diffusion, and it is geography that decides the interests of the country and is the ultimate designer of the geo-political policies of that country. So, a country with a better political situation tends to spend more on development and technological growth. According to Herrera (2003), international political systems play a crucial role in technology; similarly, geo-political relationships and competitions are significant components and major contributors to technology development and an accelerating force behind shaping technological advancement, as presented by Dahlman (2018) and Diniz (2019).

Maskus (2004) and Fink and Maskus (2005) as discussed, the TRIPS Agreement within the WTO highlights the relationship between trade agreements and intellectual property rights. These agreements can impact technology advancement, with stronger IPR protection sometimes acting as an incentive or barrier. Moreover, there is another aspect, technology imitation and intellectual property rights (IPRs). This technology imitation usually results from economic relationships and trade that increase the country's technology diffusion and adoption [Benhabib, et al., (2014)]. Branstetter, et al., (2006) studied the impacts of intellectual property rights using U.S firms' data and found that increased patent rights and royalties lead to more technological flow. Still, this phenomenon is more prominent in the case of firms in a country. Taylor (1993) highlighted the impacts of IPR and imitation in terms of the global south and north levels and pointed out that if northern firms compensate for the IPRs by limiting their technology, it will increase the north's output. Furthermore, Chen and Puttitanun (2005) observed a positive relationship between innovation and IPRs in developing countries and that better IPRs restrict imitation in developing countries and promote innovation; hence, in the case of developing countries, the implications of intellectual property rights are positive. In addition, Kelly (2009) showed that in the case of learning by imitation, technological progress and its rate depended on the population of innovators sharing the same knowledge network. In the case of trade, the greater the volume of trade, the greater the probability that producers share the knowledge.

Eaton and Kortum (1999) and Eaton (2006) studied in-country technology development and advancement. They concluded that this diffusion is localised and that there is more within-country diffusion rather than across the border, and the reason for that is more patenting than cross-border patenting. Coe and Helpman (1995) take it as the R&D expenditures and explain by taking it as the production function for the technological diffusion and as the in-country spending by the government is greater and on top of that private sector also contributes its share while on the other hand, spendings on mutual and cross-country projects are comparatively less. Although there has been a debate, the first argument has more support, endorsing that improved geo-economic relationships, geo-political conditions and better trade partnerships among countries make technology adoption significant across borders. Montobbio and Sterzi (2013) explained the role of geopolitical dynamics in adopting technology in economics through patent collaboration. Hence, it leads to technological homogeneity in the region, but the debate is still ongoing and unsettled. This research focuses on contributing its part to this regard.

Based on the aforementioned literature, the basic idea is that the impact of geo-economic relationships, geo-political security, and regional trade agreements on the country's technology adoption is still debatable, mainly when countries belong to different regional power groups. Most studies have reported a positive and significant association between technology adoption and these variables. Few studies also suggest that these variables can negatively impact country-specific conditions. Otherwise, it may be insignificant. Most importantly, although many researchers have explored the relationship between technology diffusion and regional trade agreements, the impacts of geo-economic and geo-political factors have remained under-explored as these variables have been regarded as less important. However, as these variables can have significant implications in shaping technology adoption, studying the effects of these variables is very important. Moreover, most of these previous studies have explored this topic nationally. However, there is a need for such a study that can analyze the relationship among geo-economics, geo-politics, regional trade agreements, and technology adoption across the region by comparing countries belonging to different power groups. Besides, most of the studies mentioned above revolve around studying the individual effect of these variables. At the same time, this research focuses on the combined impact of geo-economic relationships, geo-political security, and regional trade agreements on the country's level of technology adoption.

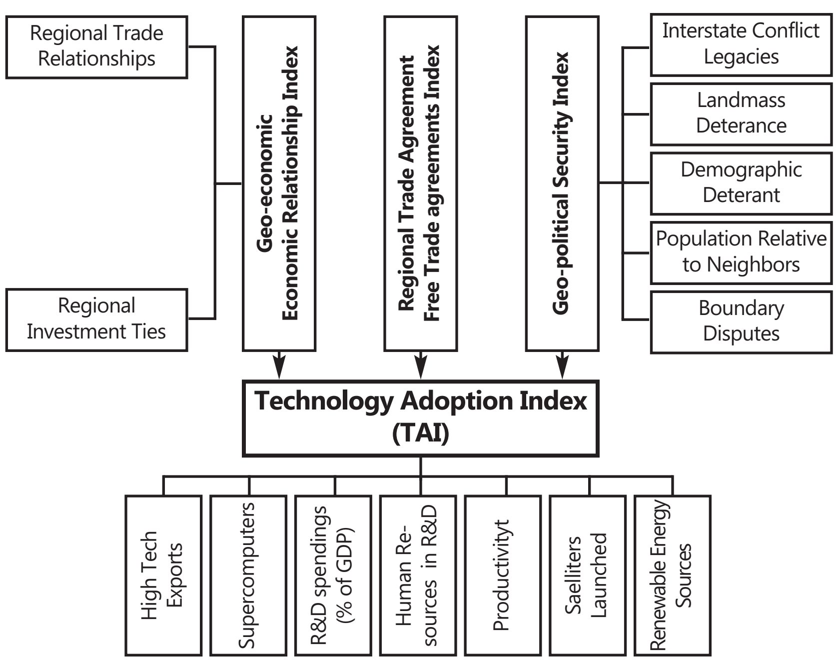
III. Theoretical Framework

Bergstrand, et al., (2015) used the gravity equation to study the effect of economic integration on trade flows. The gravity model demonstrates that countries with similar factor endowments and economic sizes are more likely to engage in substantial trade with each other [Helpman and Krugman (1985)]. Montobbio and Sterzi (2013) explained the role of geopolitical dynamics in the technology adoption through patent collaborations. Martínez-Zarzoso and Márquez-Ramos (2021) have also used the augmented form of the gravity model to explain technology flow, which eventually shapes technology adoption through direct flow and spillover of technology in the country.

Technology Diffusion Theory posits that technology can diffuse through trade, foreign direct investment (FDI), and collaboration. It often focuses on adopting and disseminating technology through communication channels, social systems, or market mechanisms. Trade agreements also facilitate technology transfer by reducing trade barriers, encouraging cross-border investments, and promoting knowledge exchange. Rogers (1983) developed the theory of diffusion of innovation, which was later used in technology, and it has since become a fundamental framework for understanding the adoption and diffusion of innovations. It also explains the adoption curve, describing how different groups, such as innovators, early adopters, early majority, late majority and laggards, adopt technology at various stages. This theory was initially more focused on the technology diffusion in-country, but later, it has also been employed in understanding cross-country technology adoption. This theory highlights that when strong economic and trade ties exist among states, they cooperate in various economic projects, transferring technology from one country to another. However, this technological diffusion is not in such a formal way; in fact, it is the result or byproduct of the different economic or trade-related agreements.

The technology spillover theory proposed by Nadiri (1993) illuminates the intricate ways knowledge originating in a specific industry, firm, or country can transcend boundaries, positively impacting diverse sectors. This theory focuses on how trade agreements, acting as catalysts for international collaboration and economic ties, significantly contribute to facilitating technology spillovers. The encouragement of cross-border cooperation within trade agreements promotes the efficient exchange of ideas and enhances the potential for synergistic efforts in technological advancements. It focuses on the unintended or indirect transfer of technology and knowledge, often by firms, industries or countries. Especially joint ventures, a common outcome of collaborative efforts encouraged by trade agreements, provide platforms for shared investments and the pooling of expertise, leading to the unintentional transfer of technological knowledge between participating entities.

Furthermore, licensing agreements facilitated by trade pacts serve as channels for the legal and regulated exchange of intellectual property, fostering a climate conducive to technology spillovers. Thus, trade agreements serve as dynamic frameworks that facilitate economic exchange and play a vital role in promoting the cross-pollination of technological know-how, ultimately contributing to global innovation and progress. Figure 1 presents a schematic representation of the study.



Source: Authors' estimation based on the Lowy Institute Asia Power Index.

FIGURE 1

Schematic Representation of the Research Framework

1. Data Collection

The study is based on the panel data analysis, and the period ranges from 2018 to 2023. Data for only 6 years for 26 countries have been taken due to availability. This includes developed and developing economies, categorised based on minor, middle, and major regional powers. All these groups have been considered so that the impact can be analysed at all different levels. Moreover, the study is based on the cross-comparison of the minor, middle, and super regional powers, categorised based on their regional influence, the data for primary variables, technology adoption index (proxy for technology adoption), economic relationship index (proxy of the geo-economics), geo-political security index (proxy for the geo-politics) and regional free trade agreement index (proxy for the regional trade agreements) has been manually extracted from the Lowy Institute Asia Power Index. Finally, data for the control variable, debt in percentage of GDP, was taken from the IMF data source. The list of variables, their sources and their definition is given in Table 1.

2. Description of Variables

The study undertakes a subgroup analysis of tech adoption; it first analyses the adoption of technology as a whole between different powers, including super, middle, and minor ones. Then, it focuses on the adoption of technology among the superpowers and minor powers separately. For this purpose, the explanatory variable taken is the technology sophistication index (TAI), which further consists of 7 indicators (hi-tech exports, supercomputers, R&D spending (% of GDP), human resources in R&D, productivity, satellites launched, and renewable energy sources). On the independent side of the model for geo-economics, the economic relationship index (ERI) is taken as a proxy further consisting of 3 sub-measures (regional trade relationships, regional investment ties, and economic diplomacy), Geo-politics measured by geo-political security index (GPSI) is used as a proxy which is composed of 5 indicators(interstate conflict legacies, landmass deterrent, demographic deterrent, population relative to neighbours, and boundary disputes). The free trade agreement index has been used to explain the dependent variable for regional trade agreements. Moreover, the gross governmental debt as a percentage of GDP has been used as a control variable to represent the overall fiscal health of the country. These proxy variables used are primarily of a composite or compound nature, i.e., they further consist of sub-variables and sub-indicators; the purpose is to holistically analyse the independent variable's impacts. Table 1 represents the composition of these proxy variables. The proxies have been used individually in various studies, while this research combines all these independent variables. It gives us insight into how technology adoption is affected by these factors. These dependent and independent variables were selected after examining the literature and data availability for different countries.

IV. Model Specifications and Estimations

The model to be estimated is below:

$$lnTA_i = \beta_0 + \beta_2 * ln\ \ ERI_i + \beta_1 * ln\ GPSI_i + \beta_3\ ln * \ \ RTAI_i + \beta_4\ ln\ *GROSSDEBT_I + \varepsilon_i$$

TAI (Technology Adoption Index) is the dependent variable representing the level of technology adoption. ERI (Economic Relationship Index) is the proxy

TABLE 1

Description of Variables, Composition and Data Sources

Variables	Definition	Data Sources	Composition of Compound variables (Sub variables, indicators with)
Technology adoptionProxy: Technology Sophistication Index (TAI)	A Technology Sophistication Index is a composite measure used to assess technological adoption and complexity within a country or region.	Lowy Institute Asia Power Index	• Hi-tech Exports Supercomputers • R&D spendings (% of GDP) • Human Resources in R&D • Productivity • Satellites launched • Renewable energy sources
Geo-politics Proxy: Geo-political Security Index (GPSI)	The Geo-political Security Index measures structural and political factors that minimise the risk of interstate conflict and enhance a country's territorial security.	Lowy Institute Asia Power Index	• Interstate conflict legacies • Landmass Deterrent • Demographic Deterrent • Population relative to Neighbors • Boundary Disputes
Geo-economics Proxy: Economic Relationship Index (ERI)	The Economic Relationship index measures the country's capacity to exercise influence and leverage through economic interdependencies.	Lowy Institute Asia Power Index	• Regional Trade Relationships • Regional Investment Ties • Economic Diplomacy
Trade Agreement Proxy:Regional Free Trade Agreement Index of the countries (RTAI)	Index based on the bilateral and multilateral free trade agreements concluded with the Index countries	Lowy Institute Asia Power Index	Free trade agreements are made by the countries in the region.
General Government Gross Debt (DEBTRATIO)	The general government debt-to-GDP ratio measures the gross debt of the general government as a percentage of GDP.	IMF Datasets	It captures the overall fiscal health of the country and its capacity to adopt technology.

Source: Authors' estimation based on the above-mentioned data sources.

for geo-economic factors, reflecting the strength of economic relationships between countries. It measures the impact of economic factors on technology adoption. GPSI (Geo-Politics Security Index) is the proxy for geo-political factors, such as security and political stability. It quantifies the influence of geo-political conditions on technology adoption. Also, the RTAI (Free Trade Agreement Index) proxy represents the influence of trade agreements on technology adoption. It quantifies the number of regional trade agreements in place. Furthermore, GROSSDEBT (Gross Debt of a country in percentage of GDP) is the control variable representing the overall fiscal health of a nation and its capacity to absorb and adopt technology. β_0, β_1, β_2, β_3 and β_4 are the coefficients to be estimated, representing the relationship between the independent variables (GPSI, ERI, RTAI, and GROSSDEBT) and the dependent variable (TAIi). Each coefficient signifies the impact of the corresponding variable on technology adoption, where β_0, β_1, β_2, β_3, β_4 > Lastly ε, there is the error term, which represents unexplained variance or other factors not included in the model.

At first, some preliminary tests were applied to check the relationship between dependent and independent variables. The correlation matrix was constructed, which showed no multicollinearity among the variables, which was the result of the variance inflation factor (VIF). Firstly, the model is estimated through the pooled OLS regression, though it fails the OLS estimation assumptions owing to heteroskedasticity, cross-sectional dependency, and serial correlation. Mainly, in a multiple linear regression model, the assumption of exogeneity is violated when a correlation exists between the regressor and the residual. In such a situation, the pooled OLS produces bias and inconsistent estimates. In addition, the problem of omitted variable bias and the possibility of specific heterogeneity are also present in the Pooled OLS estimation. Due to the above-stated concerns, the estimates fail to give a consistent and unbiased estimation of the parameters. Further, the Hausman test was applied to decide whether a correlation exists between the unique errors (unobserved individual effects) and the regressors. The test results were significant, but they rejected the null hypothesis and implied a correlation exists between the unique errors and the regressors, supporting the use of the fixed effect model. Therefore, the panel fixed effect model was applied to capture the prevailing individual fixed effects. After that, diagnostic tests of the fixed effect model were run, suggesting inefficient estimates due to serial correlation and heteroskedasticity. However, this panel data consists of a small-time (T) period, i.e. 6 years and T<N, so cross-sectional dependency or the contemporaneous correlation is not a matter of concern in this analysis. As stated by Baltagi (2008), cross-sectional dependency is a concern in the macro-panel analysis, which consists of a large number of time series. However, it is not a problem in micro-panel analysis.

V. Results and Discussion

The results of the Pooled OLS and fixed effect model for the dependent variable technology adoption index (TAI) are given in Table 2. The results of Pooled OLS for the independent variables, i.e. economic relationship index (ERI) and geo-political security index (GPSI), are significant for one variable, regional trade agreements index (RTAI), and for the control variable, which is the gross debt in percentage of GDP (GROSSDEBT) results are insignificant. However, the diagnostic tests show serious flaws in the OLS regression and reveal that it is not a better-fit model for the analysis.

TABLE 2

Estimated Results of the Econometric Analysis

Variables	Pooled OLS	Fixed Effects	Driscoll-Kraay
ERI	0.7401***	0.2032**	0.2032**
	(0.0671)	(0.0997)	(0.4942)
	[0.000]	[0.044]	[0.015]
GPSI	0.1699***	0.4970*	0.4970**
	(0.0552)	(0.2856)	(0.1574)
	[0.003]	[0.085]	[0.034]
RTAI	0.0636	-0.0931**	-0.0931**
	(0.4033)	(0.0451)	(0.0327)
	[0.117]	[0.042]	[0.046]
DEBTRATIO	0.0376	-0.0378*	-0.0378
	(0.0238)	(0.0205)	(0.0204)
	[0.116]	[0.069]	[0.138]
Constant	2.4132	10.0165	10.0165*
	(2.8668)	(9.3248)	(4.3349)
	[0.400]	[0.285]	[0.082]
F-Test	[0.0000]***		
Hausman Test		[0.000]***	
Hetero	Yes	Yes	Corrected
Autocorrelation		Yes	Corrected
CD		Yes	Corrected

Source: Authors' estimation based on econometric analysis.t

Note: . The standard errors are given in ( ), and p-values are given in [ ]. ***, **, and * indicate the significance level at 1, 5, and 10 per cent, respectively.

Thus, the fixed effect model has been applied to seek out the issue of individual fixed effects, and the results are given in Table 2. The signs of the coefficient in both regressions are mixed. After checking the diagnostic test, the results fail to support the key assumptions due to serial correlation and heteroskedasticity problems. To deal with these issues, robust standard errors are to be used through Driscoll-Kraay. This robust standard estimation technique has been applied to address these problems of autocorrelation and heteroskedasticity. This technique uses the "kernel" function to weight the residuals, making the standard errors consistent. Moreover, the test also shows the presence of cross-sectional dependence. However, it is not a matter of concern in the micro-panels; the problem is automatically corrected when the Driscoll-Kraay estimation technique is applied.

In the case of the overall analysis, the positive sign of the economic relationship index ERI indicates its positive relationship with the technology adoption index with a 5 per cent level of significance. It shows that a unit increase in the economic relationship of a country will lead to the rise in technology adoption by 0.203 units, which is in line with a study by Auty (2001). With increased economic relationships between countries, more technology spillovers and imitation occur because people start replicating the technology. Likewise, the geo-political security index has a positive relationship at 5 per cent with a coefficient of 0.4970, which means a unit change in the geo-political security of the country will cause a change of 0.497 units in the technology adoption index of a country. Keller (2002) also suggests that a better geographical situation shapes the geo-political policies of the country, which results in direct technological diffusion in the region.

Furthermore, the regional trade agreements have a negative relationship with the country's adoption of technology at a significance level of 5 percent. One unit change in the regional trade agreements decreases technological adoption among the countries by 0.0931 units. The reason for the negative relationship between technology adoption and the regional trade agreements is the high intellectual property rights restrictions among the super and middle power countries, which hinder technological diffusion, leading to less technology adoption in the region. The results support Maskus (2000) and Fink and Maskus (2005) findings. Lastly, the gross government debt GDP ratio has a coefficient of -0.037, but it is insignificant. This insignificant relationship is because private enterprises are the primary agents working in technology development and adoption in super middle and minor powers, not the government itself. Hence, the governmental fiscal conditions are not as crucial for overall interstate technology adoption when data for all three super, middle, and minor power states are taken together.

Furthermore, groupwise analysis was done for countries divided into two major categories: the super and middle regional powers and minor regional powers. In the case of the first group, the economic relationship index (ERI) has a positive relationship at a 1 per cent level of significance, and the coefficient is 0.219, which suggests that a unit increase in the economic relationship among these super and middle powers leads to a 0.219 unit increase in the technology adoption index. The reason is that a better economic relationship leads to more technology diffusion and overall spillover. In their study, Sachs and Warner (1995) have also suggested related ideas. Moreover, the geo-political security index in the case of super and middle countries is 0.4204, which is significant at 10 percent, and the relationship is positive. This shows that a unit increase in the geo-political security index of these countries leads to a 0.4204 unit increase in the technology adoption among these states, highlighting that better interstate and geo-political security of a country leads to better technology adoption capacity of the state.

The regional trade agreement index is significant at 1 per cent and negatively relates to technology adoption. The value of the coefficient, in this case, is -0.1411, and this negative relationship suggests that a one-unit increase in the regional trade agreement index among the middle and minor powers leads to a 0.141-unit decrease in technology adoption by these countries. The reason is that these countries have high intellectual property rights and are more developed and resilient, which eventually restricts the technology diffusion to other countries, as suggested by Barga and Fink (1999). The gross government debt to GDP ratio has a coefficient of -0.037 but has an insignificant relationship with the technology adoption index for super and middle regional powers. The reason is the same: private enterprises are the primary agents in technology development and adoption rather than the government itself. Hence, the governmental fiscal conditions are not as crucial for overall interstate technology adoption. In the case of minor regional powers, the economic relationship is significant at 1 per cent with a coefficient of 5.48, which means that in the case of minor countries, a unit change in the economic relationship of a country leads to an increase in the technology adoption index by 5.48. The geo-political security index has a coefficient of 2.80; when there is a unit increase in the geo-political security of a country, it causes an increase in technology adoption by 2.80 units.

The relationship between the technology adoption and the regional trade agreement index in the case of minor regional powers is 0.1178 at a 10 per cent significant level. The one-unit change in the regional trade agreement index in the case of minor regional power leads to an increase in technology adoption by 0.1178 units. Lastly, the gross governmental debt in percentage of GDP is significant at 1 per cent with a coefficient value of -0.0525, which suggests that with a unit increase in the debt to GDP ratio of the minor power countries, the technology adoption falls by 0.0525 units. The debt to GDP ratio is highly significant in the case of the minor powers because, in minor powers, governments are the primary agents of technology adoption rather than private entities. When there is an increase in the government, the government faces credit constraints to finance technology adoption. As explained by Giné and Klonner (2005), credit constraints are the primary reason for delayed technology adoption. Moreover, the Hausman test for deciding between the fixed and random effect models was not applicable in this case because it violates the basic assumptions of the test and results in the negative chi-square value. The Wald test for the groupwise heteroskedasticity has been used, which suggests the presence of heteroskedasticity and, hence, the presence of the individual effect in the data and proposed that the fixed effect model is a better fit than the random effect model. The values of the coefficient for the group-wise analysis and their level of significance are given in Table 3.

TABLE 3

Group-wise Estimated Results

Variables	Super and Middle Powers			Minor Powers		
	Pooled OLS	Fixed Effects	Driscoll-Kraay	Pooled OLS	Fixed Effects	Driscoll-Kraay
ERI	0.6509****	0.2191	0.2191***	-11.595***	5.4886	5.4886***
	(0.0771)	(0.1111)	(0.0472)	(2.7550)	(3.8123)	(0.8168)
	[0.000]	[0.053]	[0.010]	[0.000)	[0.160]	[0.003]
GPSI	0.1425**	0.42042	0.4204**	1.1282***	2.8099**	2.8009**
	(0.0620)	(0.3164)	(0.1720)	(0.2789)	(1.0618)	(0.8763)
	[0.024]	[0.189]	[0.071]	[0.000]	[0.013]	[0.033]
TAI	-0.0676	-0.1411	-0.1411**	0.2674***	0.1178	0.1178*
	(0.5970)	(0.0517)	(0.0523)	(0.0683)	(0.9565)	(0.0522)
	[0.261]	[0.008]	[0.054]	[0.000]	[0.228]	[0.087]
DEBT RATIO	0.0791**	-0.0376	-0.0376	-0.0931***	-0.0525**	-0.0525***
	(0.0302)	(0.0305)	(0.0376)	(0.0189)	(0.0248)	(0.0037)
	[0.011]	[0.223]	[0.340]	[0.000]	[0.043]	[0.00]
Constant	11.4328***	21.5302*	21.5302**	-18.1898**	-64.4999**	-64.4999**
	(4.1931)	(11.7382)	(4.8042)	(6.9566)	(26.2963)	(19.9602)
	[0.008]	[0.072]	[0.011]	[0.013]	[0.020]	[0.032]
F-Test	[0.00]***			[0.00]***		
Hausman Test		[0.00]***				
Hetero	Yes	Yes	Corrected	No	Yes	Corrected
Autocorrelation		Yes	Corrected		No	
CD		Yes	Corrected		Yes	Corrected

Source: Authors' estimation based on econometric analysis.
Note: . The standard errors are given in ( ), and p-values are given in [ ]. ***, **, and * indicate the significance level at 1, 5, and 10 per cent, respectively.

The geo-economic relationships of a country play a vital role in increasing the country's technological adoption. With more excellent economic relationships among the countries, the technology share and the technological exchange increase significantly among the countries. Better economic relationships among the countries also lead to more cross-border technology spillover and diffusion between these countries. This indirect flow is more significant between super, middle, and minor regional powers As Benhabib, et al., (2014) suggested that the flow of technology enables imitation, facilitating the advancement and dissemination of technology.

Furthermore, these relationships also help in technology adoption through increasing capacity, as better economic relationships lead to more cross-border trade among these states. Likewise, better geo-political security in the countries contributes to technology adoption in these nations. When a country has a better geo-political relationship or more geo-economic relationship, it shares the technology with other states; this is particularly true in the case of sister countries and geo-political allies. When a country is in a better relationship and is supported by the region's leading state, it supports its allies in terms of technology [Diniz (2019)].

Another critical parameter is the regional trade agreements among these states. These agreements negatively affect technological adoption between all the super, middle, and minor powers. These superpowers and middle powers have significantly developed intellectual property rights, sometimes part of these agreements. These intellectual property rights-focused terms work as the constraining force for the technology flow in these countries and, hence, limit the technology adoption of these states.

In the case of comparison among the countries, the impact of geo-economic relationships and geo-political security is higher on technology adoption in the case of minor regional powers than in the case of super and middle powers. As the already existing level of technology adoption is highly variable among the minor powers, minor changes in their geo-economic ties and geo-political security bring about more significant changes in the technology adoption of these countries. In addition, the findings show that in the case of the super and middle regional powers, the regional trade agreements have a significant but negative relationship with technology adoption. In the case of the minor regional powers, the impacts of these trade agreements are positive, and they promote technology adoption. This is due to restrictions on intellectual property rights. The first group has more developed and strict intellectual property rights, which eventually restrain and restrict technology adoption; in the second group, these rights are not strictly followed and obeyed.

Similarly, the study indicates that in the first group of super and middle powers, the debt-to-GDP ratio taken as the control variable is insignificant, suggesting that fiscal health is unimportant. Moreover, private entities and enterprises are these countries' major drivers of technology adoption. In the second group of minor powers, the debt-to-GDP ratio is highly significant and negatively affects technology adoption. That is because governments are these states' major drivers of technology adoption;

hence, overall fiscal health is essential. These econometric techniques used effectively increase the robustness of the results and provide a reliable foundation on which further conclusions can be drawn.

VI. Conclusion and Policy Recommendations

The results indicate an association of technology adoption with geo-economic relationships, geo-political security, and regional trade agreements. The geo-economic relationship has a positive relationship with technology adoption. It shows that an increased geo-economic relationship leads to more technological adoption and sophistication. Similarly, the relationship between geo-political security and technology adoption is also positive, and the greater geo-political security, the greater the technology adoption. Moreover, the regional trade agreements negatively affect the technology adoption index when data for all countries is taken together. This shows that the increase in regional trade agreements restricts technology adoption among the countries when all regional powers, super, middle, and minor, are taken together. The reason is the high intellectual property rights, which are more prominent in the super and middle regional powers than in the minor regional powers. When the data is disintegrated into two groups, including the super and middle regional powers and the minor regional powers, the empirical results show that the geo-political relationship has a positive relationship with technology adoption in both groups. Similarly, this is the case with the geo-economic relationship for both groups. The increase in these relationships leads to more technology adoption; however, the magnitude of both cases varies. For the regional trade agreements, the empirical analysis shows the varying results for both cases. For the first group, it is negatively related to technology adoption. However, in the case of the minor powers, the adoption of technology is positively affected by these regional trade agreements, as in these minor powers, the intellectual property rights restrictions are less, and hence, these agreements affect the adoption of technology positively. Lastly, the governmental debt to GDP ratio is insignificant in the case of the super and middle powers, but it is significant in the case of the minor powers. This debt-to-GDP ratio is negatively related to the technology adoption in the minor powers, as the increase in the debt-to-GDP ratio causes a decrease in the technology adoption in these minor regional powers.

The findings of the study suggest some key practical implications. At first, the combined analysis of the countries accentuates the importance of maintaining effective and good geo-economic relationships with other countries, as it confirms the importance of the geo-economic position of the country as the key factor in technology adoption. At the same time, it shows that the geo-political security of the country is also essential as it is crucial for technology adoption. That is why, considering these results, maintaining better geo-political security is also very important, and countries should focus on that. It is essential for the minor regional powers as they get more technology diffusion from major to minor inflow than minor-to-minor countries. Countries should also focus on regional trade agreements, particularly in minor countries; as for minor-to-minor technology flow, these regional trade agreements are very significant and can be crucial. In addition, the study highlights that minor regional powers should also focus on decreasing their debt-to-GDP ratio as it is negatively linked to technology adoption in these countries. The national and international policies should be made in such a way that ensures strong geo-economic relationships, better geo-political linkages and enhanced regional trade (by providing the standard levels and applicability of IPRs), which can increase the level of technology adoption and hence lead to the roadway of development There are few limitations of this study which can be explored in future. Firstly, the analysis is limited to 26 countries for 6 years because the data for the study's variables was unavailable for all other countries. Second, technology adoption can be studied from various other aspects, such as the overall technology adoption of a country, in-country technology adoption, technology adoption in different sectors, or technology adoption at the enterprise level. However, this study focuses more on the overall adoption of technology in a country, and an analysis has been done accordingly.

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