TECH INDEX PAKISTAN: A STATISTICAL APPROACH TO UNDERSTANDING THE RELATIONSHIP BETWEEN TECHNOLOGY, COMPETITION, AND GROWTH

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ABSTRACT

Given the importance of technology for economic growth and development, this research investigates Pakistan's technology landscape. A comprehensive Tech-Index has been developed to compare and evaluate Pakistan’s technology adoption and advancement level against other low-middle-income countries. These countries include Egypt, India, Sri Lanka and Uzbekistan. The index was built using secondary data from 1990 to 2022. The methodological approaches used include the EM-Algorithm for imputing missing data, Min-Max normalization for scaling, and geometric mean aggregation to create the index. The index reveals that Pakistan has modest gains in Tech-Index scores; however, these gains are relatively small compared to other South-Asian countries. Moreover, it faces significant challenges in maximizing its technology level. Key findings also indicate that countries with more R&D expenditures and a higher share of high-tech exports tend to have higher technology adoption. It also indicates that while changes in methodology can impact the rankings, the overall trends remain consistent. This index is further utilized to decompose the relationship between Pakistan’s technology landscape, market competition, and economic growth. These relationships were analyzed through 2SLS, the Toda-Yamamoto causality test, and generalized impulse response functions. The results indicate that while technological advancement negatively affects competition, growth positively depends on Pakistan's technology level. Moreover, bi-directional causality was also evident between technological advancement and economic growth, and uni-directional was evident from technological advancement to market competition.

PREFACE

The purpose of this research was multi-layered. Firstly, the aim was to construct a Tech-Index that was used then used for assessing the technological advancements and adoption level of Pakistan and for drawing a comparison to its peer countries. Secondly, the study intended to identify the relationship between technology level competition and economic growth. Lastly, it offers actionable recommendations for policymakers and stakeholders to foster a more balanced technological ecosystem in Pakistan.

We are deeply grateful to our mentors, Dr. Izza Aftab and Dr. Rabeeh Ayaz, for their invaluable guidance and support throughout this research project. Their insights and expertise have been instrumental in shaping the direction and outcomes of this study. Additionally, we extend our sincere thanks to RASTA Competitive Grants Program (CGP) for their funding and support, which made this research possible. Their commitment to advancing research in critical areas has been a significant source of encouragement and resources.

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INTRODUCTION

1.1. Technology, Competition, and Economic Growth: A Global Perspective

In today's rapidly evolving world, the increasing pervasiveness of technology and its role in shaping economic dynamics at both national and international levels has irrefutably become very significant. Countries worldwide strive to harness technology's power to drive economic growth and development. Hence, the relationship between technological innovation and economic growth has become a subject of great importance. According to the neoclassical growth theory, effective competition promotes innovation, productivity, and efficiency, leading to higher economic growth (Solow, 1956). On the other hand, market power and lack of competition can hinder economic progress by reducing incentives for firms to innovate and invest (Aghion et al., 2005). As countries compete to establish themselves as technology hubs, it is essential to have effective policies to foster healthy competition, protect consumers, and encourage innovation. Therefore, it is crucial to understand the effectiveness of technology development and adoption. Technological advancements have rapidly surged since the era of industrialization. Similarly, technology adoption has transformed various sectors of the world's economy as technology holds great potential to drive economic growth.

The global economy has witnessed several transformative technological breakthroughs, ranging from the advent of the Internet to advancements in artificial intelligence and automation. These innovations have not only redefined traditional industries but have also created entirely new economic sectors. For instance, the rise of digital platforms and e-commerce has revolutionized trade and retail, while advancements in renewable energy technologies have paved the way for sustainable economic practices. Countries that have embraced these shifts by investing in technology and fostering competitive markets have reaped significant economic benefits. For example, nations such as South Korea, Germany, and the United States have demonstrated how strategic technological investments, coupled with robust innovation ecosystems, can lead to sustained economic growth. At the same time, disparities in technology adoption highlight the importance of addressing structural barriers and capacity-building initiatives in developing countries. Despite its potential, technology's role in driving economic growth is often hindered by issues such as inadequate infrastructure, lack of skilled human capital, and policy inefficiencies. Addressing these challenges requires not only increased investment in technological infrastructure but also fostering a culture of innovation through research and development (R&D).

1.2. Pakistan's Technology Landscape: Challenges and Opportunities

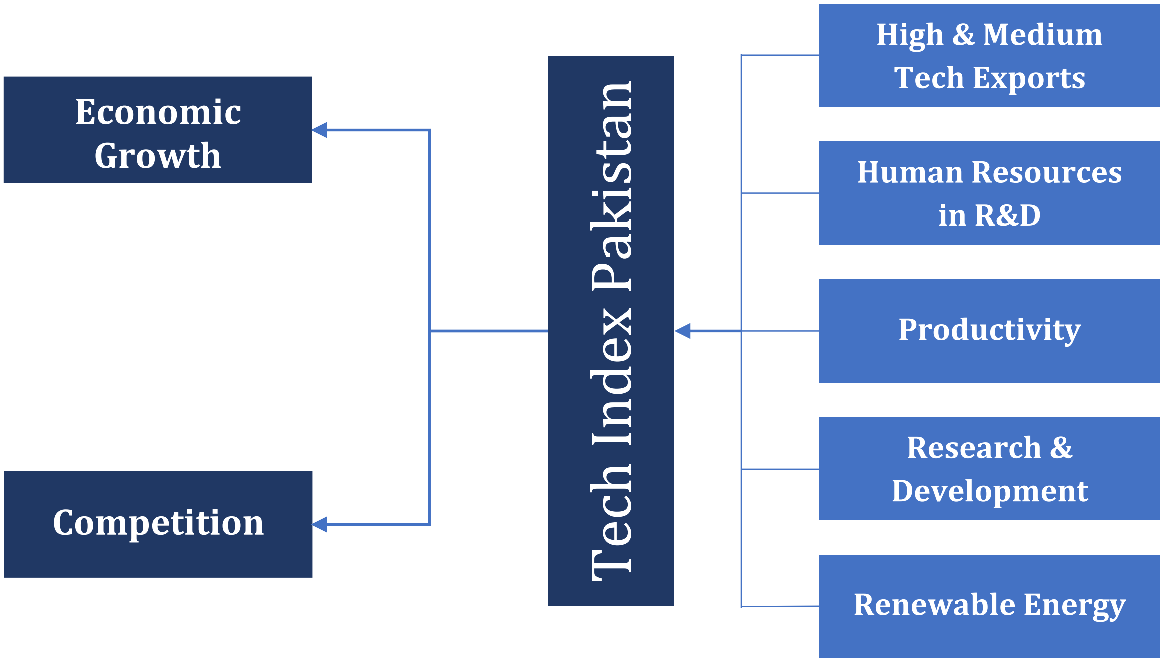
Pakistan has also witnessed significant technological advancements over the past few decades. Nonetheless, with its young and dynamic population, abundant talent pool, and growing digital infrastructure, Pakistan has the potential to become a significant player in the global technology sector. To fully realize this potential, it is crucial to understand the key indicators, challenges, and opportunities that shape the technology ecosystem in Pakistan. As Saeed & Awan (2020) have pointed out, in the case of Pakistan, research and development R&D boosts the GDP. The technology landscape in Pakistan is marked by a unique set of opportunities and constraints. On the one hand, the proliferation of mobile and broadband internet has expanded access to digital services, creating a foundation for innovation and entrepreneurship. Initiatives such as the Digital Pakistan Policy and the establishment of Special Technology Zones reflect the government's commitment to fostering technological growth. However, a deeper analysis reveals persistent challenges, such as limited R&D expenditure, inadequate STEM education, and a regulatory framework that often stifles innovation rather than nurturing it.

The role of the private sector in driving technological adoption and innovation also cannot be overlooked. While Pakistan has seen the emergence of several tech startups and IT services firms, scaling these initiatives remains a challenge due to the lack of venture capital, mentorship, and market access. Despite the growing importance of technology, a better understanding of its impact on economic parameters remains understated. Thus, Pakistan still faces many challenges in completely exploiting the resources for technological development, adversely impacting economic growth. Acknowledging these challenges, infrastructure gaps, and lack of competition is also very important as it sets the stage for identifying opportunities. Therefore, this research aims to propose targeted solutions and interventions by examining obstacles impeding technology-driven competition and growth.

1.3. Building a Tech Index: Rationale and Approach

The rationale behind this study is rooted in the pressing need to understand the role of technology in driving economic competitiveness and growth. Thus, the primary objective of this research project was to develop the technology index for Pakistan. This technology index depicts the country's overall situation concerning technology adoption, advancement, and proliferation. By thoroughly examining the dynamics of technological sophistication and competition, we tried to uncover how technological advancements shape the competitive market landscape. The intention was to gauge the technological landscape's depth and breadth by examining the prevalence of advanced technologies and digital infrastructure and synthesizing the findings into data-driven recommendations. These recommendations have been tailored for policymakers, industry stakeholders, and investors, providing pragmatic insights into leveraging technology for enhanced competition and sustainable economic growth in Pakistan. Figure 1 represents the schematic representation of the project. It shows the Tech Index's composition, which comprises five sub-variables and the post index estimation framework of this study.

Figure 1: Schematic Depiction of the Research Project



This research study was focused on finding answers to the following research questions, firstly what is the current situation of technology adoption and advancement in Pakistan, and how does this contribute to the current growth? How does technology-driven innovation contribute to competitive advantage within specific industries in Pakistan? By exploring the relationship between technology-driven innovation and competitive advantage, this part focuses on uncovering the key factors that propel specific industries ahead of others. Lastly, what is the correlation between technological sophistication, market competition, and overall economic growth in Pakistan? This question aims to comprehensively understand the relationships between technology investment, competition, and economic development.

1.4. Scope and Policy Relevance of the Study

The scope of the study lies in the absence of a comprehensive understanding of how technology, competition, and economic growth intersect in Pakistan. While technology adoption is on the rise, its implications for the competitive side and overall economic growth remain understudied. Thus, this research addresses the critical gap in knowledge by digging into the intricate relationships between these three pillars. The problem encompassed the need to decode how variations in technology adoption, innovation strategies, and investment patterns contribute to or hinder market competition and economic growth. The study aimed to catalyze a systematic exploration beyond surface-level observations through such an approach. The ultimate goal was to provide actionable insights grounded in robust statistical analysis that can inform strategic decisions, policies, and investments to propel Pakistan toward a more technologically advanced and economically vibrant future.

This research holds profound significance in shaping and refining public policy in the country. As Pakistan strives for economic growth and technological advancement, the findings of this study can significantly determine and inform actionable recommendations for policymakers. This research provides a comprehensive and analytical framework to understand Pakistan's overall technology outlook through a technology index. Besides, it is also helpful in understanding how technology penetration is interplaying and whether it significantly contributes to sectoral growth. The study contributes to formulating innovation and technology policies that favour market competition and economic growth by examining the relationship between technological innovation, innovation competition, and economic growth. Policymakers can leverage insights into the factors driving market competition to incentivize and support innovation, thus catalyzing economic growth. The research sheds light on the dynamics of market competition influenced by technology. Policymakers can use these insights to formulate competition policies that ensure fair markets, encourage healthy competition, and foster economic growth. Understanding the correlation between technology investment, competition, and economic growth is essential for optimizing investment policies. It will help to bridge the digital divide, promote digital literacy, and ensure that the benefits of technological growth are accessible to all segments of society.

The remainder of the study is organized as follows: Section 2 reviews the literature on circular debt in Pakistan. Section 3 presents the methodology with data sources. Section 4 describes the findings and discusses them. Section 6 presents the following steps and further plans for the study.

LITERATURE REVIEW

This part provides an overview of existing literature. It examines current technology indices' development and limitations and explores the complex interrelationship between technology, competition, and economic growth. The aim is to identify gaps and limitations in the existing research, particularly concerning the context of Pakistan.

2.1.2. Limitations of Previously Existing Indices

In recent years, various indices have been introduced by many scholars and organizations to understand the technology levels and the interrelationship between technology and multiple variables. Most are very specific, covering only one aspect rather than presenting a holistic picture. For example, the Global Innovation Index (calculated by the World Intellectual Property Organization WIPO) focuses on innovation side majorly, the Index of Technology Progress developed by Rodríguez & Wilson (2000) focuses on ICT and technology consumption, and Technology Index Warner (2000) uses technology transfer Index or Innovation Index. Moreover, all these indices are limited to specific years and countries, mainly not including Pakistan. Therefore, this project focuses on developing a single composite index that covers most technology-related aspects and serves as the starting point for creating reliable and effective policies.

2.2. Technology, Growth and Competition

As far as the connection between technology, competition, and economic growth is concerned, many scholars have tried to examine this relationship. Few of them have focused on the micro level by investigating the relationship between the intensity of competition, advanced manufacturing technology, and how it affects organizational performance, and they conclude that a positive relationship exists between these variables (Fuadah et al. 2014). Similarly, existing literature also demonstrates a growing interest in technology adoption within emerging economies. Studies by Bujari & Martínez (2016) and Dereli (2019) present the transformative impact of technology on economic development, emphasizing the need for high-level tech in national contexts and highlighting that the production and export of the high-level tech add up to great value to the overall GDP, hence speed up the economic growth. The development of such technologies, intensification of R&D, and increase in patent applications are therefore crucial to achieving economic growth.

The early supporters of the Schumpeterian growth models, Grossman & Helpman (1991), predicted that innovation and growth should decline with competition because more competition reduces the rents that reward successful innovators. Later on, Aghion et al. (2001) developed new models of competition and presented the idea of economic growth through "escape-competition" and presented that there is the possibility that more competition could encourage innovation as the competition may increase the incremental profits from innovating, which eventually promotes the R&D investments as each firm will try to acquire the leads in technology over its rival. Gomaa (2014) also suggested the exact relationship between competition and economic growth and concluded that domestic competition complements an economy's growth rate.

Nevertheless, another side supports the belief that there has been a significant decrease in competition in many countries, impacting inclusive growth. This decline in competition intensity can be seen in the increase in market concentration as well as the ability of firms to influence prices or market power. This literature presents how important competition is for growth (Aghion et al., 2021). Other empirical studies have also provided mixed findings regarding the impact of competition on economic growth. Some studies suggest a positive relationship between competition and growth (Buccirossi et al., 2013; Nicoletti and Scarpetta, 2005), while others find no significant relationship (Baldwin & Forslid, 2000; Griffith et al., 2004). The literature above provides valuable insights into the relationship between technology, competition and economic growth. Only a few studies offer real insight, particularly to the context of Pakistan. The present literature also lacks sector-specific analyses, limiting a comprehensive understanding of the dynamics at play. Moreover, most studies focus on developed economies, thus demanding research on Pakistan's unique challenges and opportunities.

METHODOLOGY AND DATA SOURCES

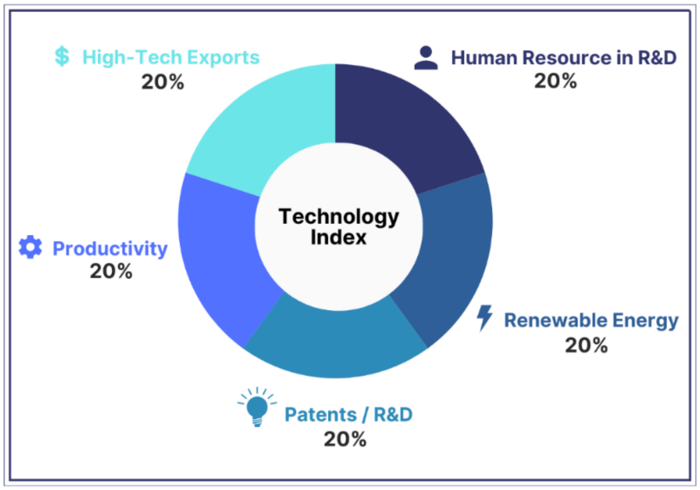
3.1. Methodology

The primary aim of this study was to comprehend the intricate associations between technology, market competition, and economic growth. Since, it is of utmost importance for Pakistan to harness the advantages of technological advancement while upholding a competitive and sustainable market atmosphere. Therefore, for such objectives, the primary step was to develop a measure of technology that gauges the country's technological adoption and advancement level over the years. Thus, this study first developed the Tech Index, which provided annual ratings of technological sophistication for Pakistan from 1990 to 2022. The index was built for five nations: Egypt, India, Pakistan, Sri Lanka, and Uzbekistan. The aim of creating an index for such a cross-section was to perform uncertainty and sensitivity analysis to analyze the index's robustness. After the index formation, the relationship between technological advancement, market competition, and economic growth was analyzed using different econometric techniques. The data collection on all the variables came from secondary sources such as the UNDP, World Development Indicators, UNIDO, UNESCO, ILOSTAT, and WIPO. Tables 1-2 in Appendix I highlight the variables, their definitions, and their sources, such that Table 1 highlights the variables utilized to make the Tech Index. In contrast, Table 2 highlights the variables used in the study's econometric analysis. The following section outlines the data collection methods, design and composition, and analytical techniques for creating the index and econometric methods for analyzing the relationships.

3.2. Tech Index Composition

The technology index captures the country's overall technological sophistication. It encompasses intellectual outputs, commitment to innovation, adopting advanced practices, the efficiency of production processes, competitiveness in high-tech trade, and the human capital dedicated to research and development. The primary foundation for the composition has been taken from the Lowy Institute Asia Power Index and modified according to the context of Pakistan. The index by Lowy Institute consists of 8 sub-indicators of technology, including Hi-tech exports, Productivity, R&D Expenditures, Human Resources in R&D, Nobel Prizes (Science), Supercomputers, Satellites launched, and Renewable energy. As for Pakistan, some sub-indicators such as Nobel Prizes (Science), Supercomputers, and Satellites launched are inapplicable, so they have been neglected. However, the remaining five sub-indicators have been assigned an equal weightage of 20%, following Lowy Institute's index, to develop the tech index. The composition and the weightage of the sub-indicators are shown in Figure 2.

Figure 2: Composition of Tech Index (Sub-indicators and Weightage Scheme)



Two indices have been developed. The first index is almost the exact replication of the Lowy Institute's technology sub-indicator. However, in constructing the second index, residents' patent applications were used as a substitute for R&D expenditures due to significant missing data for R&D, especially for Pakistan. Although statistical imputation techniques addressed the missingness, imputed values might still not perfectly capture the actual trends. Thus, given these constraints, patent data provided a viable alternative for measuring technological sophistication. Meanwhile, patents and R&D are also widely accepted proxies for technological advancement since both capture different but complementary dimensions of technological advancements. R&D expenditures reflect the financial and resource inputs allocated toward innovation activities, such as scientific research and technological development, while patent applications serve as an output-based measure, representing tangible outcomes of these innovative efforts (Smith et al., 2021; Potepa & Welch, 2017). Thus, by incorporating patent data into the index, we aim to mitigate the potential biases introduced by imputed data while maintaining a robust measure of technological sophistication. Moreover, patents not only measure innovation outcomes but also directly influence market competition. They create exclusionary rights, establish barriers to entry, and shape competitive dynamics by granting monopolistic advantages or fostering innovation clusters. Hence, given the study's object of analyzing market competition, the use of patents might also offer additional benefits, such as more direct insights into competitive changes and disturbances. For sub-indicators, proxies have been taken. Data for these proxies have been extracted from various resources, including UNIDO, UNESCO, ILOSTAT, WIPO, and the World Development Indicators. The proxies, their definitions, and sources are given in Table 1. The model for the calculation of the tech index is as follows;

Tech Index with patents;

$$Tech\ Index = f(EXP, PROD, PATENT, HR, RENEW) \qquad \text{... Index 1}$$

Where the index calculation based on the geometric mean is as follows;

$$Tech\ Index = \sqrt[5]{(0.20 * EXP).(0.20 * PROD).(0.20 * PATENT).(0.20 * HR).(0.20 * RENEW)}$$

Tech Index with R&D expenditures;

$$Tech\ Index = f(EXP, PROD, R\&D, HR, RENEW) \qquad \text{... Index 2}$$

Similarly, as earlier;

$$Tech\ Index = \sqrt[5]{(0.20 * EXP).(0.20 * PROD).(0.20 * R\&D).(0.20 * HR).(0.20 * RENEW)}$$

Where EXP indicates Medium and High Technology Exports, PROD indicates Productivity, PATENT stands for Patent Applications, R&D stands for Research and Development Expenditures, HR indicates Human Resources in R&D, and RENEW indicates Renewable Energy. Both of these indices were built for five different nations, including Pakistan. These nations include Egypt, India, Sri Lanka, and Uzbekistan. These countries are lower-middle-income countries per the World Bank's 2024 classification. Pakistan, India, and Sri Lanka are South Asian countries, Egypt is a North African country, and Uzbekistan is a Central Asian country.

3.3. Construction of Tech Index

The creation of the Tech Index was followed using the guidelines of the OECD/JRC Handbook on Constructing Composite Indicators has been followed (OECD/European Union/EC-JRC, 2008). The index was built in R using the COINr package.

3.3.1. Data Imputation Methods

The first step in constructing any index is imputing missing data, if any. However, before using any data imputation method, as it is good to determine whether the missingness in the data is due to MCAR (Missing Completely at Random), MAR (Missing at Random), or MNAR (Missing Not at Random). Given that we had economic data for lower-middle-income countries with significant missing data for the Number of Researchers and R&D Expenditure, we assumed that our data is MAR. According to the OECD/JRC Handbook, missing data imputation falls under two domains: implicit and explicit modeling. Implicit imputation techniques like Hot Deck Imputation, Substitution, and Cold Deck Substitution are not based on statistical procedures. In contrast, explicit imputation techniques are statistically based and include mean/median/mode imputation, regression imputation, the expectation-maximization (EM) algorithm, and multiple imputation. Multiple imputation is often considered the most robust approach for MAR data. However, it is inapplicable because it creates numerous complete datasets through an iterative process and then pools the regression results from all datasets. Since the study does not directly run any regression analyses but is instead interested in making a composite index and performing uncertainty and sensitivity analyses, multiple imputations become inapplicable. Therefore, we opted for the EM-Algorithm to impute missing values. The EM-Algorithm performs well under MAR conditions and is considered superior to listwise and pairwise deletion, mean/median/mode substitution, and even regression imputation, nonetheless, as human resource is stock variable so it was simply imputed for the missing values before applying EM- algorithan for the rest of the variables. (Li et al., 2024; Dong & Peng, 2013; Nelwamondo et al., 2007; Schafer & Graham, 2002; Ghahramani & Jordan, 1993).

3.3.2. Data Normalization, Weighing, & Aggregation Scheme

After imputing the data, the next step in constructing a composite index is normalization. Normalization scales different variables to a standard scale. Various normalization techniques include Min-Max (Minimum-Maximum), Z-Scores, and Distance to Target Country. However, we used the Min-Max approach because it provides a clear and intuitive range (1 to 100) for comparing index scores over the years and against countries. Thus, it aligns to make the index scores comparable across countries and makes it easy to communicate. The Z-Score normalization, which normalizes data with a mean of 0 and a standard deviation of 1, could result in index scores of an undefined range and even in negative scores, thus making the results difficult to communicate and interpret. However, the Distance to Target Country approach requires a reference country for benchmarking. Thus, it made the Min-Max approach the most straightforward and meaningful for our purposes. The next step was determining the appropriate weights for each indicator. We used equal weights for each indicator following the Lowy Institute Power Index. The final stage of construction was selecting the aggregation method. Various aggregation methods exist, such as arithmetic mean, geometric mean, and harmonic mean. The geometric mean has been used because it is more robust to extreme values and better balances the contributions of different indicators. This method is beneficial when indicators have different units and scales. The harmonic mean, however, is extremely sensitive to zero and minimal values, which can distort the index (Greco et al., 2018; OECD/European Union/EC-JRC, 2008).

3.3.3. Uncertainty and Sensitivity Analysis

After constructing a composite index, it is necessary to check its robustness through uncertainty and sensitivity analyses. As uncertainty analysis (UA) studies how input changes affect the composite index value. Also, sensitivity analysis (SA) quantifies the amount of output variance attributed to such uncertainties (Saisana et al., 2005). Thus, these analyses were performed by challenging the key assumptions and steps taken to create the Tech-Index, including the normalization step, the weighting scheme, and the aggregation method. For normalization, we consider how using Z-Scores instead of the Min-Max method affects the index. For weighting schemes, 100 replications were produced by randomly applying 25% noise to the original indicator weights. Finally, the arithmetic instead of geometric mean was also considered for the aggregation method. However, it is worth mentioning that the application of uncertainty and sensitivity analyses is typically considered for composite indices constructed at a single point in time, such as cross-sectional data. However, since the study has panel data, directly applying these analyses is not feasible. Therefore, we considered uncertainty and sensitivity analyses at three different points in time: 2000, 2010, and 2020.

3.4. Model Specification

The motive of the study was also to discern a relationship between technological advancement, market competition, and economic growth. Since, technology adoption and advancement also play a significant role in enhancing economic competition. This project was focused on analyzing this impact in the context of Pakistan. Besides analyzing the interlinks between market competition and technological advancements, given the significance of technology for economic growth. It analyzed the relationship between market competition, technological advancement, and Pakistan's economic progress. Thus, based on the past literature and given relatively few degrees of freedom for our econometric models, our hypothetical model for market competition and economic growth could take the following functional form;

$$Competition = f(TI, HDI, FDI) \qquad \text{... Model 1}$$

$$Economic\ Growth = f(Comp, TI, HDI, FDI) \qquad \text{... Model 2}$$

Where Competition is the market competition proxied by the industrial design applications, industrial design application aims to protect the ornate and aesthetic aspects of products rather than their functionality. These design applications could be used as a proxy for market competition, given that firms in competitive industries frequently depend on distinctive product designs to captivate consumers and safeguard their market positions. Thus, an increase in these applications indicates endeavors for product distinction, innovation to acquire market share, and the strategic employment of intellectual property to deter imitation, signifying heightened rivalry. Besides, TI is the Tech Index developed in this study, HDI is the human development index, and FDI is the foreign direct investment. Economic growth is proxied by the country's gross domestic product (GDP). The variables, their definitions, and sources are also presented in Table 2.

In model 1, for evaluating the effects of technology on competition, competition was treated as the dependent variable, while the independent included tech index, human capital development, and foreign direct investment. Similarly, for model 2, economic growth was the dependent variable, tech index and competition were core independent variables, human capital development was a mediating variable, and foreign direct investment was the control variable. Both models' competition and economic growth variables have been log-transformed to ensure consistency and comparability across all variables. Additionally, taking the log of competition and economic growth is supported by the fact that both variables are limited dependent variables. This transformation made our models semi-log and allows for a general non-linear framework. The rest of the variables in the study were already an index or in percentage form; for example, FDI is represented as foreign direct investment inflows in percentage of GDP, and HDI and TI are both indices based upon the geometric mean. The above models were analyzed using different econometric techniques such as two-stage least squares, granger causality, and impulse response functions. The details on the econometric methodology are in the following sections.

3.5. Econometric Methodology

This study employed various econometric techniques including the Ordinary Least Square (OLS), Two stage Least Square (2SLS), also checked for the causality and used the Impulse Response functions to check for the shocks due to change in the variables.

3.5.1. Two Stage Least Square (2SLS) Estimation

Two-Stage Least Squares (2SLS) is a widely used econometric technique to address endogeneity issues in regression models. Endogeneity arises when one or more explanatory variables are correlated with the error term, violating the assumption of exogeneity required for ordinary least squares (OLS) estimation. This issue leads to biased and inconsistent parameter estimates, distorting causal inference. In economic growth studies, endogeneity is particularly common due to feedback loops between growth and its determinants, omitted variables, and measurement errors (Moaniba et al., 2018; Swamy & Fikkert, 2002; Romer, 1989). Thus, it was theoretically motivating to use 2SLS because economic growth often exhibits simultaneity and dynamic relationships. Moreover, this study's Granger causality tests revealed reverse causality between technological innovation and GDP, where GDP causes innovation. Thus, such feedback loops necessitate using 2SLS to obtain consistent causal effect estimates. Under such instances, the 2SLS can lead to consistent estimates as it operates in two stages to deal with endogenous variables. In the first stage, the endogenous variable is regressed on exogenous and instrumental variables (IVs) to isolate the variation unrelated to the error term. The second stage used the predicted values from the first stage as a regressor in the main equation to estimate its causal effect on the actual dependent variable. However, for the consistency of 2SLS, the selection of instrumental variables is critical, as they must satisfy two conditions: relevance (significant correlation with the endogenous variable) and exogeneity (no correlation with the error term). In this study, since it was nearly impossible to identify appropriate instruments for variables such as the tech index —an aggregate measure that incorporates multiple dimensions of technological innovation — particularly given that existing studies often rely solely on patents as a proxy for technological innovation, we employed the lags of the endogenous variables as instruments. Recognizing these limitations, we employed the first lags of the endogenous variables as instruments, a common practice in the literature. However, for the validity of this approach, the lagged variables must meet the relevance and exogeneity conditions. The basic framework of the 2SLS model can be understood using the following notions: Consider a simple regression model as follows;

$$y_1 = \beta_0 + \beta_1 x_1 + \beta_2 z_1 + \cdots + \beta_{k-1} z_{k-1} + \mu_1 \qquad \text{... equ 1}$$

Where y_1 is the dependent variable, x_1 is the endogenous variable, and z's are the exogenous variables. Besides, β's represents intercept and slope parameters and μ_1 is the error term. Now, due to the endogenous nature of x_1 variable, the exogeneity condition of OLS is violated such that the covariance between x_1 and μ_1 is not zero, which renders OLS estimators inconsistent. The 2SLS can lead to consistent estimates by estimating the above model in two stages. The first stage (reduced form regression) can be estimated as follows;

$$\hat{x}_1 = \alpha_0 + \hat{\alpha}_1 z_1 + \cdots + \hat{\alpha}_{k-1} z_{k-1} + \hat{\alpha}_k z_k + \varepsilon \qquad \text{... equ 2}$$

Where $\hat{x}_1$ is the endogenous variable and is only predicted the exogenous information. z_k is an additional exogenous variable and does act as an instrument. Besides, the rest of the parameters and variables are the same as defined earlier. Now, the equation 1 can be re-estimated using the prediction of x_1 ($\hat{x}_1$) which is exogenous. The prediction of x_1 is exogenous since it is purged of its endogenous part, which is the error term, and now it solely relies on the exogenous information. Thus, the second stage of 2SLS can be estimated as follows;

$$y_1 = \beta_0 + \beta_1 \hat{x}_1 + \beta_2 z_1 + \cdots + \beta_{k-1} z_{k-1} + \mu \qquad \text{... equ 3}$$

Where all the variables and parameters are the same as explained earlier, and $\hat{x}_1$ is the prediction of x_1. Therefore, the estimation of 2SLS can yield consistent estimates in the presence of endogeneity; however, the instruments must be relevant and exogenous.

3.5.2. Granger Causality Analysis

This study also employed the Granger non-causality test to analyze causal linkages and determine the direction of causation. Causality often denotes the directed relationship between two variables, where changes in one variable led to or predict changes in another. Establishing causal links is essential in empirical studies, especially in growth models, to comprehend how technological sophistication, market competitiveness, and economic growth interact. Conventional Granger causality tests are extensively employed for this objective; however, they necessitate pre-testing for stationarity, rendering them susceptible to the model's order of integration. To overcome these limitations, this study employed the Toda-Yamamoto causality test, which offers a robust framework for causality analysis without requiring pre-tests for stationarity. Similarly, it minimizes the risks of model misspecification due to pre-testing biases. Toda & Yamamoto (1995) proposed employs a modified vector autoregressive (VAR) model that integrates the system's variables' maximum order of integration, d_{max}. Consequently, the Toda-Yamamoto methodology guarantees accurate inference by preserving the asymptotic distribution of the Wald test statistic, even in the presence of non-stationary series or data integrated at varying orders. The general framework of the Toda-Yamamoto causality test can be articulated as follows:

$$y_t = \alpha_0 + \sum_{l=1}^{q} \alpha_l y_{t-l} + \sum_{l=1}^{q} \beta_l x_{t-l} + \sum_{j=q+1}^{q+d_{max}} \beta_j x_{t-j} + \sum_{j=q+1}^{q+d_{max}} \alpha_j y_{t-j} + \varepsilon_t \qquad \text{... equ. 4}$$

Where α and β represent the parameters, d_{max} denotes the maximum order of integration, and q indicates the optimal lag number. The parameters of the additional lagged variables are incorporated into the model as exogenous variables, excluding them from Wald's restriction test. The null hypothesis posits that x does not Granger-cause y, or $M_{x \rightarrow y} = 0$.

3.5.3. Impulse Response Functions

This study also established a vector autoregressive (VAR) model to examine impulse response functions, which are crucial instruments in time-series models for assessing the dynamic behavior of a system in reaction to shocks or innovations. Specifically, an IRF traces the effect of a one-time shock to one variable on the current and future values of all other variables in the system. The use of IRFs offers numerous advantages. First, IRFs account for the endogenous nature of the relationships among variables, enabling the identification of both direct and indirect effects. Second, they provide a time horizon for the impact of shocks, which is critical for understanding the persistence of effects. Finally, IRFs allow for a simultaneous examination of multiple interrelated variables, which are crucial in systems characterized by feedback loops, as with technological advancement, market competition, and economic growth. This study used accumulated impulse response functions to capture the cumulative impacts of a shock over time, rendering them especially valuable for analyzing the long-term consequences of technological progress and market competition on economic growth. The impulse response functions estimated in this study are derived from the generalized impulses introduced by Koop et al. (1996). This method accounts for the intricate interdependencies of the variables without enforcing limiting assumptions regarding their sequence, resulting in more resilient and comprehensible outcomes. Consequently, Generalized IRFs provide more reliable estimates than orthogonal IRFs (Ewing, 2003). Besides, the response standard errors of IRFs were bootstrapped utilizing Kilian's (1998) bias-corrected confidence interval for small sample sizes. Thus, this method has been shown to provide unbiased estimates, particularly in small sample sizes like the 33-year dataset utilized in this research. Whereas the basic bivariate VAR model with only one lag can be defined as follows;

$$y_t = \alpha_1 + \beta_{11} y_{t-1} + \beta_{12} x_{t-1} + \mu_t \qquad \text{... equ. 5}$$

$$x_t = \alpha_1 + \beta_{21} x_{t-1} + \beta_{22} y_{t-1} + v_t \qquad \text{... equ. 6}$$

Where y_t and x_t indicates that the variables' current values depend upon their past values and on the past values of the other variable.

RESULTS AND DISCUSSIONS

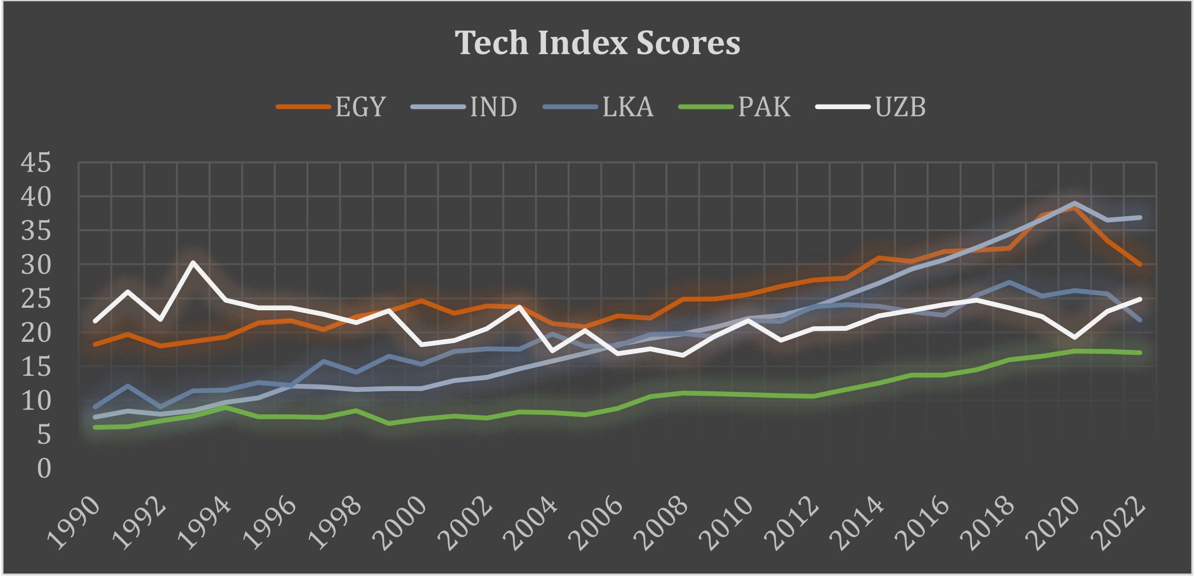
This section presents and discusses the study's empirical findings based on the methodology prescribed in the previous section.

4.1. Tech Index Pakistan

This section discusses the study's initial results, primarily of the Tech Index. As previously discussed, two indices were developed initially. One with the Patents variable (Index 1) and the other with the R&D Expenditures (Index 2) as attached in Appendix II as Table 3. The methodology for both indices is precisely the same as explained previously. However, this section focuses and advances exclusively on the results derived from Index 1, constructed using patent data, for four key reasons. First, uncertainty analysis demonstrated that Index 1 exhibited more admirable stability over time, with less sensitivity to changes in its formation assumptions. Second, Index 1 aligns more closely with the scores and ratings of other established technology indices, such as the Global Innovation Index. Third, it is potentially less biased, as it relies less on data imputation techniques. Finally, as previously discussed, using patents in Index 1 provides more direct and reliable insights into market competition dynamics. The uncertainty and sensitivity analysis results for both indices are attached in Appendix III. In Index 1, the uncertainty analysis reveals that changing the index methodology could impact the countries' index scores in 2000 and 2020; it could impact the scores of two countries by two points. In 2010, it can impact the scores of four countries. Similarly, the uncertainty analysis for Index 2 reveals that changing the index methodology could affect the index scores of three countries in 2000, 2010, and 2020. The sensitivity analysis of both indices shows different results for each point in time. For index 1, it can be generalized that over the years, all three, the weighting, normalization, and aggregation scheme are important and can induce variance in the index scores. Similarly, for index 2, all three choices of weighting, normalization, and aggregation methods can induce much variance. However, the variance induced by the assumptions of index two results in higher uncertainty in index two scores compared to index one overall.

Figure 3 presents Index 1 scores for five countries, including Egypt, India, Pakistan, Sri Lanka, and Uzbekistan, from 1990 to 2022. Based upon Index 1, Pakistan has witnessed consistent but modest growth, peaking in 2020 at 17.22. Significant growth phases were observed from 1990 to 1994, 2005 to 2007, and 2012 to 2020. Meanwhile, in 1990, Sri Lanka and India started relatively just above Pakistan, such that the scores of India and Sri Lanka were 7.50 and 9.02, whereas that of Pakistan was 5.99. After 33 years, in 2022, India and Sri Lanka scored relatively much better than Pakistan at 36.89 and 21.81, where Pakistan scored 17. India has experienced an upward trend and shows signs of consistent growth from 1990 onwards. Sri Lanka also showed a positive growth trend but was modest compared to India. Its trajectory slowed and flattened, especially after 2012, and after an abrupt upsurge from 2016 to 2018, it started a declining trend until the end of 2022. Egypt also showed modest growth in its tech index scores. It showed a significant growth trend in its scores after 2007 but relatively slowed and started declining after 2019. Uzbekistan showed many sudden and abrupt fluctuations, improvements, and declines in its tech index scores; however, it shows an overall declining trend over the years. The analysis of the line charts for the Tech Index reveals several key findings. Firstly, India's consistent improvement and achievement of high-tech index values indicate a strong level of technological advancements and implementation of the technology adoption framework. It suggests India has effectively leveraged its policy framework to develop and maintain a leading position among the selected countries. Sri Lanka's stagnant growth, particularly in the latter half of the period, highlights substantial obstacles to adopting and reaping the effects of technological change. It suggests a lack of efforts to enhance their technology ecosystems. Egypt showed significant growth, particularly in the latter half of the period, highlighting substantial improvements in technological infrastructure. It suggests a focused effort to enhance their technology ecosystems. While showing growth, Pakistan has had more modest increases and has experienced slower growth in recent years. It indicates potential challenges that have been faced, possibly due to economic or infrastructural constraints. At last, Uzbekistan showed a declining trend, suggesting the country's inability to adapt, upgrade, and maintain with the world's changing technological landscape.

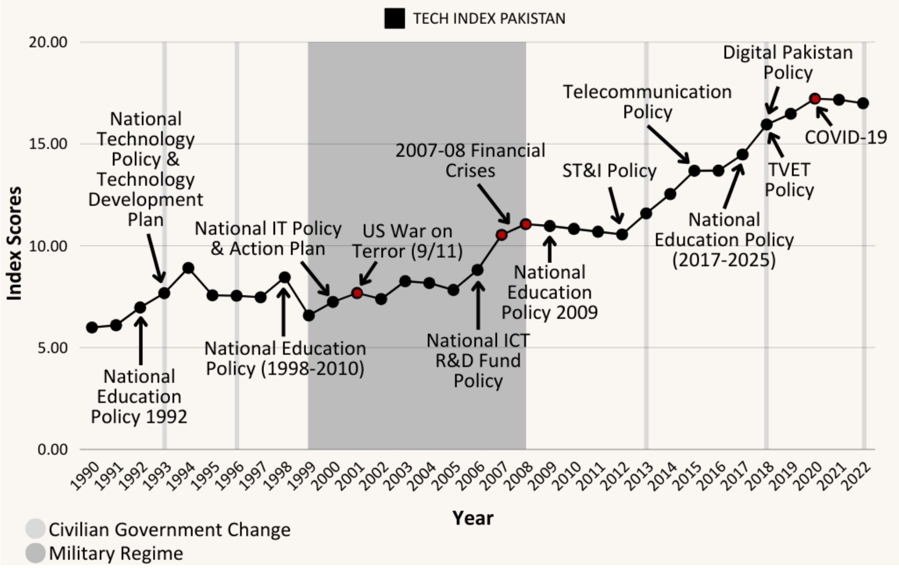
Figure 3: Tech Index Scores (Comparison between Five Countries across Time)



4.2. Impact of Policy Shocks on Tech Index: A Comparative Analysis

After estimating the Tech index next step was to check the impact of policies, initiatives adopted by the governments on the tech index. Figures 4-7 explain the fluctuations in the tech index as the results of these technology and innovation relative initiatives and policies as well as the impacts of exogenous factors. Pakistan's policy interventions in the technological domain show mixed outcomes with notable fluctuations in the Tech Index. During periods of government focus on technology, such as the launch of the Digital Pakistan Policy 2018 and the establishment of Special Technology Zones, the index demonstrated upward trends. The lag effect is particularly evident as the initiatives required time for implementation and resource allocation. However, inconsistency in governance and political instability during transitions of government limited the momentum of these policies. For example, the alternating leadership between civilian and military governments disrupted long-term planning, leading to stagnant or even declining index values. The graphs also reveal that despite attempts to enhance R&D capacity and promote digital infrastructure, the lack of substantial funding and weak institutional frameworks hindered sustained growth. While temporary improvements were noted during phases of focused government initiatives, such as the National Science, Technology, and Innovation Policy 2012, these gains were short-lived due to inadequate follow-through and resource constraints. The fluctuating trends reflect the absence of cohesive and long-term strategies for technology-driven growth, as shown in Figure 4.

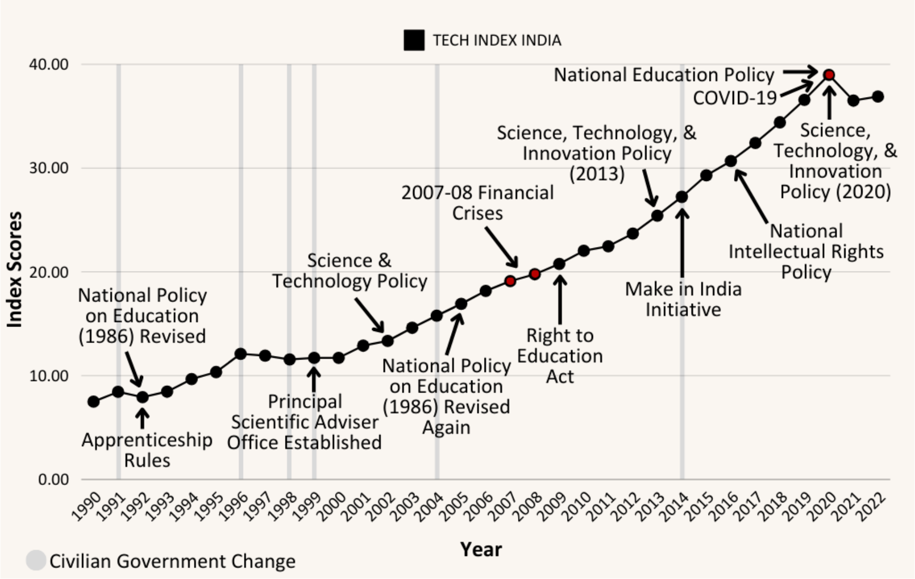
Figure 4: Impact of Policy shocks and Exogenous Changes on Tech Index of Pakistan



Source: Authors' owns compilation.

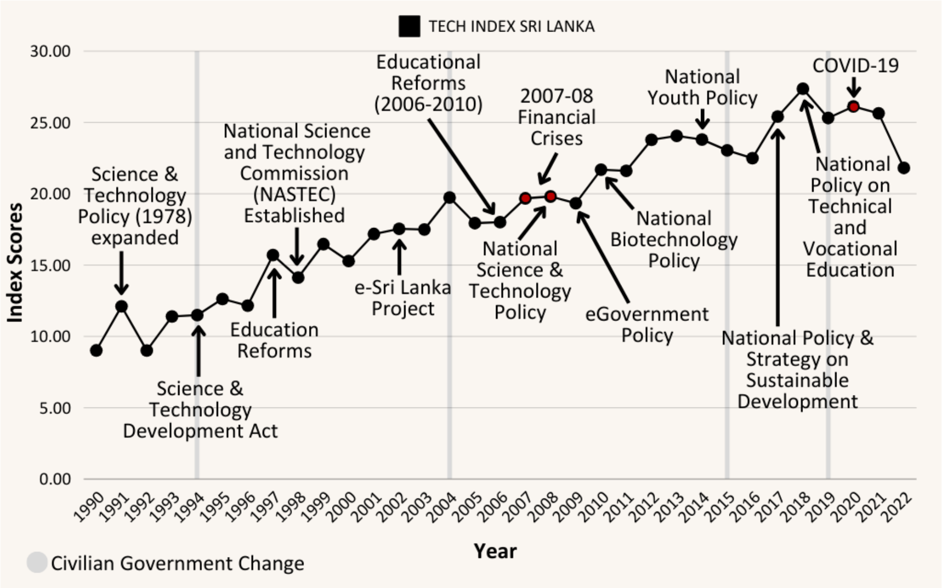
In the case of India, India's Tech Index exhibits a more consistent upward trajectory, reflecting the successful implementation of strategic policies. Key initiatives like the National Intellectual Property Rights (IPR) Policy 2016, the Make in India campaign 2014, and Digital India 2015 catalyzed significant growth in technological advancement. Unlike Pakistan, India's political stability and strong institutional support enabled these policies to yield sustainable impacts. The graphs show a lagged effect following the adoption of major policies, such as the Make in India initiative, which initially did not impact the index significantly but contributed to substantial growth in subsequent years. This highlights the importance of continuity in governance and focused execution. The performance under the leadership of Prime Minister Narendra Modi, with a strong emphasis on technology-driven development, further solidified the country's competitive position. Consistent funding for R&D and skill development programs played a pivotal role in maintaining the upward trend as shown in Figure 5.

Figure 5: Impact of Policy shocks and Exogenous Changes on Tech Index of India



Sri Lanka's Tech Index reflects modest but steady growth, with the country experiencing gradual improvements in technological advancement following specific policy interventions. The adoption of the Science, Technology, and Innovation Strategy (2011–2015) and the National Policy on High-Tech Industries 2016 contributed significantly to enhancing human resources in R&D and high-tech exports. The graphs demonstrate that the implementation of these policies often exhibited a lag effect, with noticeable impacts on the Tech Index appearing in subsequent years as the initiatives gained traction. During periods of political and economic stability, such as the early 2010s, Sri Lanka made strides in promoting digital infrastructure and high-tech manufacturing. The establishment of institutions supporting R&D further solidified the country's commitment to fostering innovation. However, the pace of growth slowed during periods of political upheaval, highlighting the challenges of sustaining long-term strategies in a fluctuating governance environment. The graphs also reveal that Sri Lanka's renewable energy adoption policies, particularly under the Sri Lanka Sustainable Energy Authority Act 2007, positively influenced the Tech Index as shown in Figure 6. This initiative supported the gradual transition to sustainable energy sources, though its impacts were more pronounced in later years as renewable energy projects scaled up. The relatively slow implementation of these projects limited immediate gains but provided a foundation for future growth.

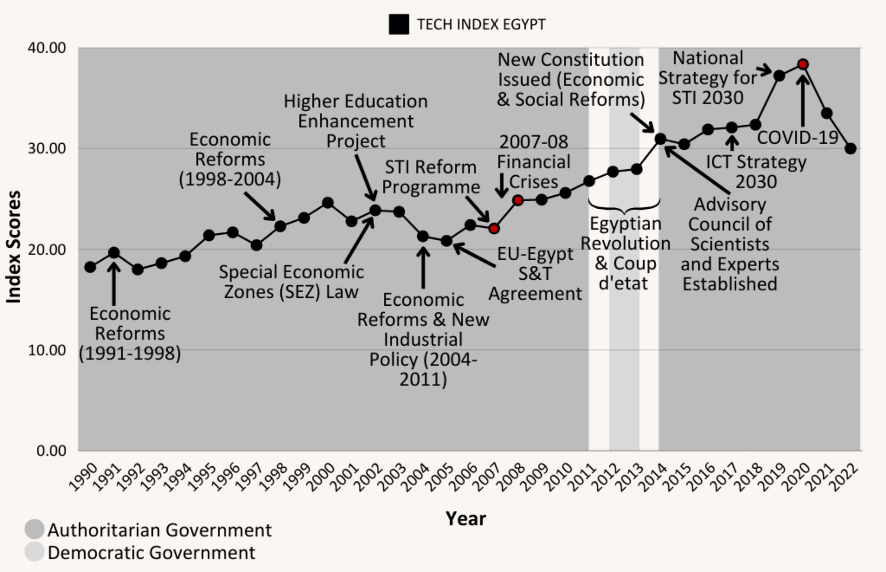
Figure 6: Impact of Policy shocks and Exogenous Changes on Tech Index of Sri Lanka



Source: Authors' owns compilation.

Furthermore, Egypt's performance reveals steady growth, with notable improvements following key policy interventions. The adoption of the Sustainable Energy Strategy 2035 (2016) and the Egypt Innovate Initiative 2015 significantly enhanced technology adoption and innovation capacity. Similar to India, Egypt experienced a lag effect, as these policies gradually improved the Tech Index over subsequent years. The graphs highlight that period of political stability under President Abdel Fattah el-Sisi provided a conducive environment for policy implementation, allowing long-term plans like Vision 2030 to take shape. While initial growth was moderate, consistent efforts in fostering public-private partnerships and attracting foreign investment bolstered the index's growth. Egypt's ability to integrate policy planning with economic goals played a crucial role in sustaining technological advancement.

Figure 7: Impact of Policy shocks and Exogenous Changes on Tech Index of Egypt



Source: Authors' owns compilation.

4.3. Two Stage Least Square (2 SLS)

This section analyzes the relationship between technological advancement, market competition, and economic growth through least square regressions. However, due to the potential endogeneity problem, the two-stage least square has been estimated besides the ordinary least square for both models 1 and 2.

4.3.1. Estimates of Model 1 (Relationship between Technology Index and Competition)

The estimates of model 1, in which the impact of technological advancement, foreign direct investment, and human development index is analyzed on market competition, are attached in Table 4 (in Appendix 4). Similarly, the estimates of model 2 are attached in Table 5 (in Appendix 4) which shows the impact of technological advancement, market competition, foreign direct investment, and human development index on economic growth. In model 2, a first lag of dependent variable (GDP) is also utilized as an independent variable, accounting for unobserved dynamic processes that could cause residuals to be correlated over time. So, this strategy helped mitigate the serial correlation problem by reducing it to marginal significance (10% level). Moreover, as discussed earlier, economic growth often exhibits inertia, where past growth influences current growth. Thus, theoretical and econometric reasonings motivate using lagged dependent variables in the second model. In contrast, a lag of dependent variable as an independent variable has not been introduced in the first model because market competition is often more susceptible to immediate changes due to policy shifts, market entry or exit, and competitive strategies. Similarly, even sudden technological innovations can disrupt market dynamics, leading to rapid changes in competitive landscapes. Therefore, past competition may not adequately explain current competition levels, making the inclusion of a lagged dependent variable less theoretically justified in the first model. Moreover, model 1 was less susceptible to the problem of serial correlation; thus, there was even no econometric justification for using the lagged dependent variable in the first model.

The regression estimates of model 1 reveal similar insights when estimated using OLS and 2SLS. Where 2SLS has been utilized to control the endogenous nature of the FDI variable, as found by the Toda Yamamoto causality analysis as given in Table 6 (in Appendix 4). The estimates indicate that the technology index (TI) has a negative and statistically significant relationship with market competition in both models. In the OLS estimation, the coefficient for TI is -0.0539 (significant at the 10% level), while in the 2SLS estimation, the coefficient is -0.0578 (also significant at the 10% level). This suggests that higher technological innovation may initially reduce market competition, possibly due to increased market concentration by technology leaders or barriers to entry created by technological advancements. The FDI variable has a negative but statistically insignificant coefficient in both models, with values of -0.0257 in the OLS model and -0.0697 in the 2SLS model. These findings imply that foreign direct investment does not directly affect market competition within the sample. In contrast, HDI also demonstrates a strong positive and highly significant relationship with market competition in both models. The OLS estimate shows a coefficient of 11.4919, while the 2SLS estimate is 11.5123, both significant at the 1% level. These results highlight the critical role of human development in enhancing market competition, likely through the promotion of skilled labor, innovation, and institutional quality, which foster competitive market environments. The constant term (C) is positive but statistically insignificant in both models, suggesting no substantial baseline effect on market competition beyond the variables included in the models.

Regarding model fit, the R-squared values for both OLS (0.7664) and 2SLS (0.7426) indicate that the independent variables explain a substantial portion of the variation in market competition. The F-statistics for both models are highly significant at the 1% level, affirming the joint significance of the explanatory variables. The Durbin-Wu-Hausman endogeneity test for the 2SLS model yields a p-value of 0.5601, indicating strong evidence of endogeneity of the FDI variable and advocating using the 2SLS model over the OLS. However, the Cragg-Donald F-statistic of 44.8064 exceeds the threshold of 10 and Stock-Yogo critical values at 10%, 15%, 20%, and 25%; thus, suggests that the chosen instrument (lagged FDI) is strong and relevant. Besides, the Durbin-Watson statistics (1.7657 for OLS and 1.7968 for 2SLS) indicate no severe autocorrelation issues. However, the Breusch-Pagan serial correlation LM test is significant at the 10% level for the OLS model (5.9059), suggesting the presence of mild serial correlation. In the 2SLS model, this issue is not pronounced (3.8768, not significant). In order to cure the problem of serial correlation in the OLS model, the Newey-West Heteroskedastic and Autocorrelation Consistent (HAC) standard errors were utilized. Besides, the Breusch-Pagan-Godfrey heteroskedasticity test shows no evidence of heteroskedasticity in either model. Finally, the Jarque-Bera test indicates that the residuals are normally distributed in both models, as evidenced by non-significant statistics (1.9686 for OLS and 1.0119 for 2SLS).

4.3.2. Estimates of Model 2 (Relationship between Economic Growth (GDP), Competition and Technology Index)

The regression analysis results for the relationship between GDP and its explanatory variables are attached in Table 5 and provide several critical insights. The regression estimates of both OLS and 2SLS employ Newey-West HAC standard errors to correct for heteroskedasticity and autocorrelation. The 2SLS model accounts for the potential endogeneity of FDI and TI by using their first lags as instruments chosen for their presumed correlation with the endogenous variables and uncorrelation with the error term. The estimated coefficients from Table 5 (in Appendix 4) reveal interesting dynamics. The market competition (COMP) variable is insignificant in both the OLS and 2SLS models, suggesting a negligible role for market competition in economic growth under simple regression assumptions. Similarly, FDI has a negative coefficient in both models, though it is statistically insignificant. This result implies that foreign direct investment may not have a direct, immediate impact on economic growth in the sample, potentially due to inefficiencies in capital allocation or delayed spillover effects. In contrast, the TI variable consistently shows a significant and positive impact on GDP across both models. The coefficient increases from 0.0036 in the OLS model to 0.0065 in the 2SLS model, highlighting the critical role of technological advancement in driving economic growth. Besides, under the 2SLS framework, the variable becomes statistically significant at a 1% significance level instead of 10%. Similarly, HDI is positively and significantly associated with GDP, with coefficients of 2.0663 and 2.3756 in the OLS and 2SLS models, respectively. This underscores the importance of human capital development in enhancing a country's productive capacity and long-term economic performance. The lagged GDP term [GDP(-1)] is also highly significant in both models, with coefficients of 0.6989 (OLS) and 0.6306 (2SLS), indicating the persistence of economic growth over time. The constant term is also significant in both models, reflecting baseline factors contributing to GDP growth that are not captured by the included variables.

The diagnostic statistics further validate the models' performance. The R-squared values are exceptionally high for both models, at 0.9982 and 0.9981, respectively, suggesting that the models explain nearly all variation in GDP, which might be since HDI uses per capita income as one of its primary constituents in describing human development index. Besides, the F-statistics of both models are significant at the 1% level, confirming the joint significance of the independent variables. For the 2SLS model, the Durbin-Wu-Hausman endogeneity test results are insignificant and support the hypothesis that FDI and TI are endogenous, justifying the use of the 2SLS framework over the OLS. The Cragg-Donald F-statistic (12.9024) exceeds the threshold of 10 and Stock-Yogo critical values at 10%, 15%, 20%, and 25%, thus indicating that the chosen instruments (lagged values of FDI and TI) are strong and relevant. Even after using the first lag of the dependent variable, the Breusch-Pagan Serial Correlation LM test indicates the presence of serial correlation, although at a weaker significance level (10%). Similarly, the Breusch-Pagan-Godfrey test confirms the presence of heteroskedasticity. However, both issues were dealt with using HAC standard errors. Finally, the Jarque-Bera test results suggest that the residuals are normally distributed, as evidenced by non-significant p-values (0.2698 and 0.2151 for OLS and 2SLS, respectively).

4.4. Causal Relationship between Technology, Economic Growth and Competition (Toda Yamamoto Causality)

The results of the Toda-Yamamoto causality test are attached in Table 6 (in Appendix 4) and provide valuable insights into the complex relationships between technological innovation (TI), foreign direct investment (FDI), human development (HDI), market competition (COMP), and GDP. The findings show that technological innovation Granger-causes GDP and market competition at a 10% significance level, indicating its critical role in driving economic growth and fostering a competitive business environment. This underscores the importance of investing in technological advancements, as they not only improve productivity but also create disruptive changes that reshape market dynamics. Furthermore, HDI Granger causes GDP and FDI at a 10% significance level, highlighting how improvements in human development indicators, such as education, health, and income levels, play a pivotal role in enhancing economic growth and attracting foreign investments. This suggests that policies to improve human capital can yield significant dividends in terms of economic and investment outcomes. Meanwhile, GDP is also shown to Granger-cause FDI and TI at 1% and 10% significance levels, which indicates that higher economic growth attracts foreign investments and fosters technological advancements. This relationship emphasizes the need for a stable macroeconomic environment to stimulate innovation and foreign investment. Additionally, market competition Granger causes FDI at a 5% level, suggesting that a competitive market environment attracts foreign investors because it signals openness, opportunity, and economic vibrancy. However, the test also reveals several non-significant relationships. For instance, FDI does not Granger-cause GDP, which implies that the direct impact of foreign investments on economic growth might depend on the quality and efficiency of investment allocation. Similarly, HDI, market competition, and FDI do not significantly influence technological innovation, indicating that technological advancements might be driven more by internal factors such as R&D expenditure, institutional support, or innovation systems rather than external market or development indicators.

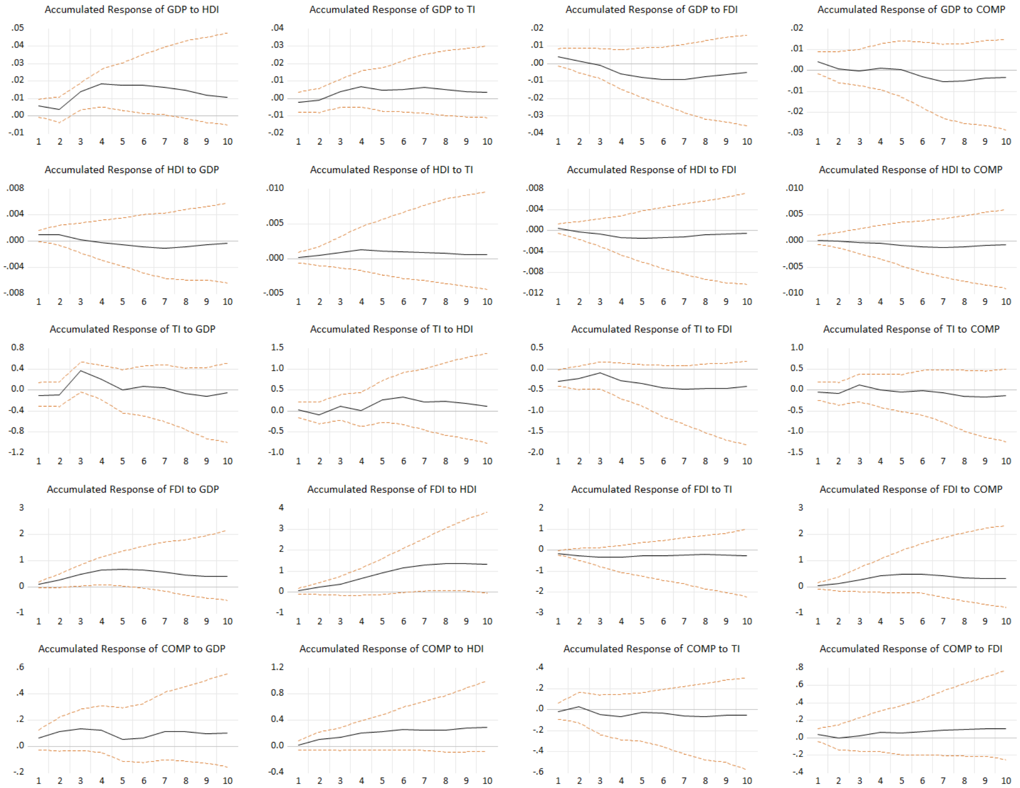
4.5. Generalized Impulse Response Functions

The results of the Generalized Impulse Response Functions (GIRFs) provide valuable insights into the dynamic relationships among economic growth, human development (HDI), technological innovation (TI), foreign direct investment (FDI), and market competition (COMP). The accumulated responses to one standard deviation shock reveal the temporal effects of these variables on one another, shedding light on their economic interactions and policy implications. The response spans over ten periods, with the 95% confidence intervals computed using Kilian's (1998) bias-corrected bootstrap methodology for small sample sizes and is based on 999 bootstrap replications and 499 double bootstrap replications. The solid black line represents the accumulated response of the variable to the shock in other variables. In contrast, the dashed orange lines indicate the 95% confidence interval, capturing the range within which the response is expected to fall. The accumulated response of GDP to shocks in HDI shows a short to medium-term positive effect. Initially, the response is close to zero. However, it becomes positive and significant around the third period, peaking around the fifth period before stabilizing and slightly declining over time. However, it stays largely positive until the end of the 10th period. It suggests that improvements in human development contribute significantly to economic growth. Similarly, GDP also responds positively to shocks in technological advancements.

The initial response of GDP to the innovation is slightly negative but turns positive around the second period, increasing steadily and peaking at approximately the fourth period. Beyond this point, the response stabilizes and slightly declines over time. These results suggest that technological innovation exerts a delayed but positive effect on GDP in the short to medium term, aligning with theoretical expectations that innovations enhance productivity and economic growth. However, the impact of technological innovation is not as strong as that of the human development index. Meanwhile, the FDI shock has an initial positive but quickly negative and persistent impact on GDP, potentially reflecting inefficiencies in the absorption of foreign investments or structural economic challenges. Finally, market competition shock has a negligible impact on GDP, but the GDP response turns slightly negative after the fifth period. Meanwhile, the response of HDI to shocks in any of the variables within the system is minimal, with the response line consistently hovering close to the zero axis. This indicates that human development and capital improvements are primarily unresponsive to changes in economic growth, technological innovation, foreign investment, and market competition.

The response of technological innovation to GDP shocks is initially slightly negative, but after the second period, it starts to increase rapidly and reaches a maximum in the third period; after that, the shock starts to die as the response line nears the zero axis for the rest of the period. The significant positive impact shows that economic growth supports innovation through enhanced resources and opportunities. Initially, HDI shocks induce almost no response to technological advancements. However, after the fourth period, the response is significant and positive, reinforcing the mutually beneficial relationship between human capital and technological progress. The accumulated response of technological advancement to FDI is negative throughout, with the most substantial negative effect occurring between the sixth and ninth periods, which suggests that foreign investments may focus on resource extraction or low-tech industries, which could suppress domestic innovation efforts. At last, shock in the market competition has a negligible impact on the levels of technological innovation as the response line nears the zero axis throughout the period. For FDI, shocks in GDP, HDI, and COMP lead to a steadily increasing positive response in FDI, reflecting that economic growth, human development, and market competition attract foreign investment. Conversely, technological innovation shocks result in a weaker but negative response throughout, suggesting that rapid advancements may create uncertainty for foreign investors or increase entry costs. Finally, market competition exhibits a positive response to GDP shocks, peaking around the third period and sustaining till the end, indicating that economic growth fosters competitive market structures. HDI shocks also elicit a steadily increasing positive response in competition, suggesting that human development enhances market dynamics. Technological innovation shock results in a weaker but persistent negative response from market competition, reflecting that innovation reduces and eases competitive pressures. FDI shocks induce a weak but persistent positive response in competition, implying that foreign investments might create balances and distort market concentration.

Figure 8: Generalized Impulse Response Functions


Accumulated Response of GDP to HDI
Accumulated Response of GDP to TI
Accumulated Response of GDP to FDI
Accumulated Response of GDP to COMP
Accumulated Response of HDI to GDP
Accumulated Response of HDI to TI
Accumulated Response of HDI to FDI
Accumulated Response of HDI to COMP
Accumulated Response of TI to GDP
Accumulated Response of TI to HDI
Accumulated Response of TI to FDI
Accumulated Response of TI to COMP
Accumulated Response of FDI to GDP
Accumulated Response of FDI to HDI
Accumulated Response of FDI to TI
Accumulated Response of FDI to COMP
Accumulated Response of COMP to GDP
Accumulated Response of COMP to HDI
Accumulated Response of COMP to TI
Accumulated Response of COMP to FDI

CONCLUSION

This research comprehensively evaluated Pakistan's technological landscape through the development of a Tech Index, facilitating a comparative analysis with other lower-middle-income countries, including Egypt, India, Sri Lanka, and Uzbekistan. The findings highlight that while Pakistan has demonstrated consistent growth in its technological sophistication over the past three decades, it remains significantly behind its peers in key sub-indicators such as patents, high-tech exports, labor productivity, human resources in R&D, and renewable energy adoption. Results point out that countries with high R&D investment and a focus on high-tech exports tend to lead others in the level of technological advancement. The better performance by India and Egypt is explained by strategic policies, including strong intellectual property regimes and skill development programs, along with focused investment in renewable energy and high-tech industries. On the other hand, Pakistan lags because of systemic challenges of underfunding of R&D, poor institutional framework, and restriction of policies on the encouragement of innovation and competition. Econometric analyses were conducted to determine the complicated relationships between technological advancement, competition, and economic growth. In addition to that, econometric analyses revealed the intricate relationships between technological advancement, competition, and economic growth. While technological innovation positively contributes to GDP growth, its initial impact on market competition appears to be negative, possibly due to increased market concentration and barriers to entry. The findings also underscore the significant role of human capital development in fostering both competition and economic growth, highlighting the need for policies that prioritize education, skill development, and R&D capacity-building. The Generalized Impulse Response Functions demonstrated the long-term positive impacts of technological innovation and human development on economic growth, while also revealing the dynamics between competition, FDI, and technology adoption.

This research emphasizes the urgent need for Pakistan to adopt a holistic and integrated approach to technological development. Drawing lessons from the success stories of India and Egypt, Pakistan must focus on increasing R&D investments, enhancing its patent ecosystem, promoting high-tech exports, and fostering renewable energy adoption. Addressing structural barriers such as regulatory inefficiencies, inadequate funding, and lack of stakeholder collaboration will be critical for closing the technology gap with its regional peers. In conclusion, the Tech Index serves as both a diagnostic and strategic tool, offering valuable insights for policymakers, stakeholders, and industry leaders to design targeted interventions. By leveraging technology as a driver of economic growth and competition, Pakistan has the potential to transform its technological landscape and achieve sustainable development in the coming decades.

POLICY RECOMMENDATIONS AND FUTURE DIRECTIONS

This study highlights that Pakistan remains significantly behind in technology adoption and advancement, a gap that has adversely impacted the country's economic growth. The lack of progress in embracing and implementing advanced technologies has limited Pakistan's ability to compete globally and capitalize on opportunities for innovation-driven development. As a result, the technological stagnation continues to act as a barrier to achieving sustainable economic growth and improving the nation's competitive standing, while its peer countries are more focused and has better technology levels which are contributing significantly towards growth of these countries. In order to draw better and actionable policy recommendation it is irrefutably necessary to first understand what these other countries are doing that Pakistan is missing and then what can be the possible pathway to Pakistan which can be adopted. This part first provides the cross- country comparison between the tech index performances and the policy differences, then next part provides the actionable policy recommendations that can be followed in order to get better outcomes.

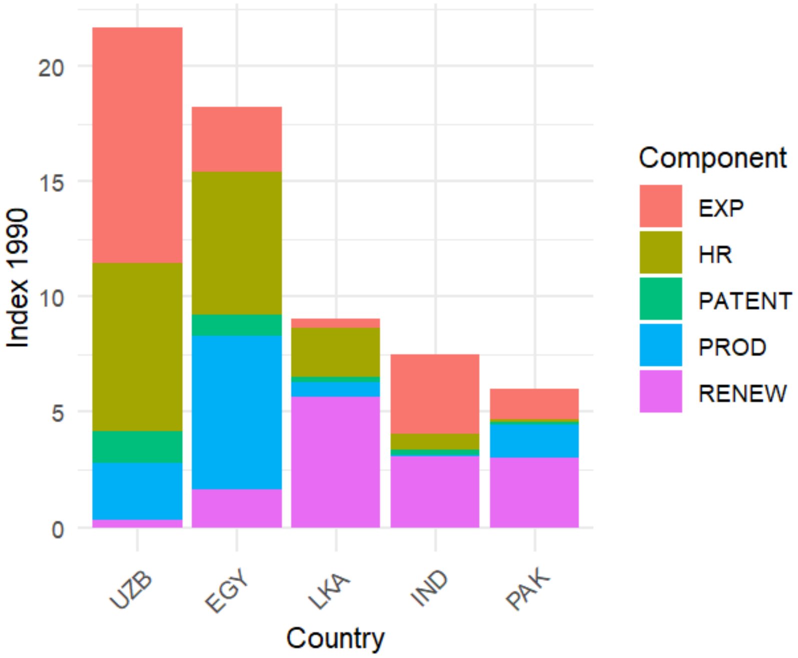
6.1. Technology Index Performance: Cross-Country Comparisons and Policy Differences

This part focuses on drawing a comparison between the countries and tries to explain the differences not only at the index level but also explains how other countries successfully adopted policies that stimulated increase in the technology level and why Pakistan is lagging behind in this context. Over the eight years examined, graphs reveal that India and Egypt have consistently shown upward trends in all sub-indicators, whereas Pakistan's progress has been uneven. This reflects structural weaknesses in Pakistan's innovation and industrial strategies, coupled with limited international collaborations and lack of regional integration in key sectors. Firstly, as shown the Figure 9 high-tech exports as a share of total exports are markedly higher in India and Egypt, driven by government initiatives like India's "Make in India" campaign and Egypt's Industrial Modernization Program (IMP). These programs offer tax breaks, export subsidies, and incentives for technology-driven industries. Conversely, Pakistan's reliance on traditional low-value industries like textiles undermines its ability to achieve similar levels of high-tech exports. Limited R&D in export sectors and weak integration into global value chains are critical constraints. Furthermore, India and Egypt outperform Pakistan significantly in patent registration. India's National IPR Policy, 2016, promotes innovation through financial incentives and a supportive legal framework for patent filing; hence, there is consistent growth in patent applications. Egypt offers customized support to startups and individuals for intellectual property filings through the Technology Innovation and Entrepreneurship Center (TIEC). In Pakistan, there are no accessible mechanisms, and public awareness is very limited. Similarly, institutional support is weak, which results in very minimal patent activity. Other than that, India and Egypt always show consistent higher labor productivity, which is due to focused workforce development programs. India's Skill India Mission and Egypt's National Employment Strategy have made a point of upskilling and reskilling programs for youth and people from other marginalized groups. In Pakistan, labor productivity has mostly been stagnant due to an education system that does not match market needs, limited skill development initiatives, and weak industrial automation.

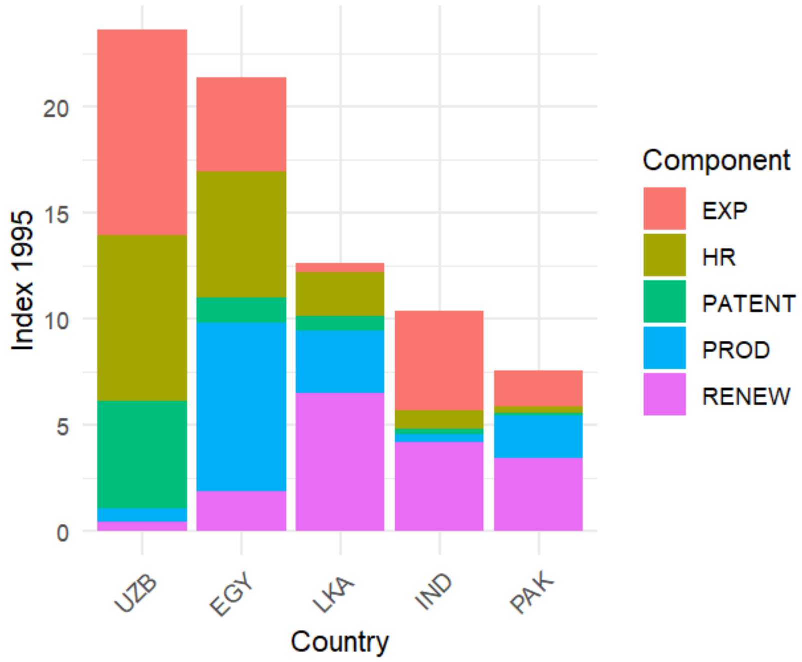
Furthermore, India's investment in scientific research through institutions like the Indian Institutes of Technology (IITs) and the establishment of the National Innovation Council have increased its R&D workforce significantly. Egypt's National Strategy for Scientific Research 2019 has similarly emphasized creating a robust research ecosystem. Pakistan's inconsistent funding for education and research, coupled with brain drain and poor infrastructure for R&D, leads to a significantly lower density of researchers per million people. Transition to renewable energy supported by government is another major factor in this regard. As, Egypt and India lead in renewable energy adoption, supported by large-scale projects like Egypt's Benban Solar Park and India's National Solar Mission. These initiatives include public-private partnerships and financial incentives to boost renewable energy capacity. Pakistan, despite launching the Alternative and Renewable Energy Policy 2019, struggles with implementation due to regulatory hurdles, reliance on fossil fuels, and inadequate investment in renewable projects. The comparative performance highlights a need for Pakistan to diversify its industrial and technological base. For example, India's focus on IT and Egypt's emphasis on energy innovation underline the importance of sector-specific policies, a critical area where Pakistan has lagged.

Figure 9: Comparative Composition of Tech Index and Contribution of Each Constituting Sub-Indicators

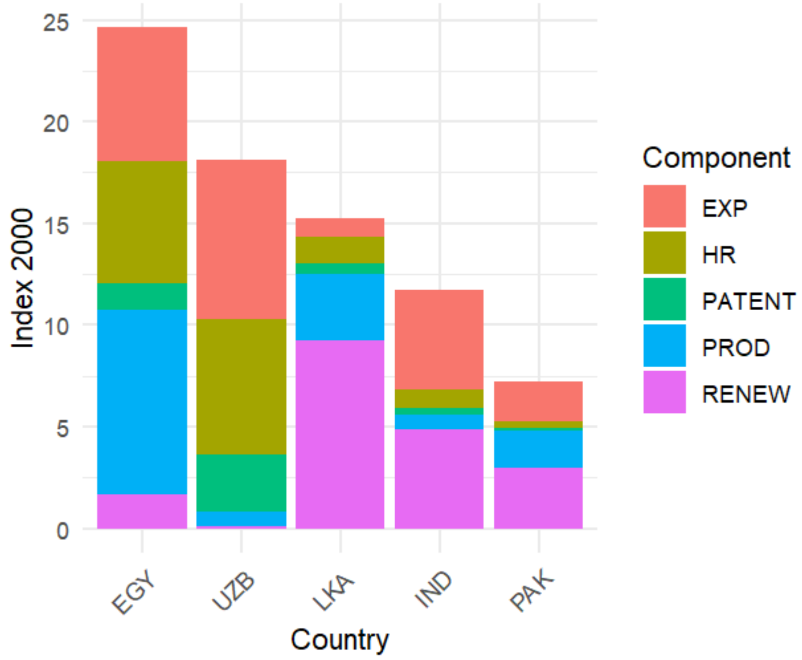
Graph 1



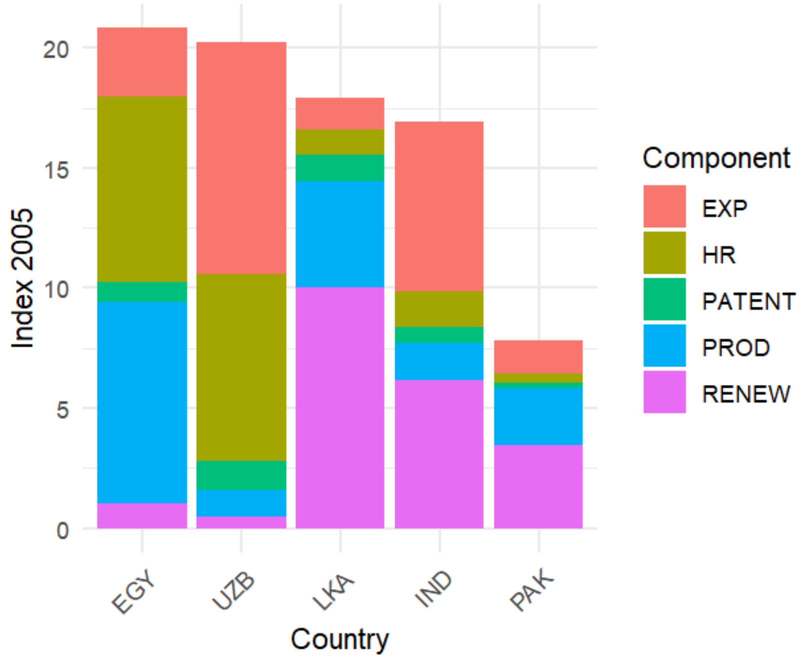
Graph 2



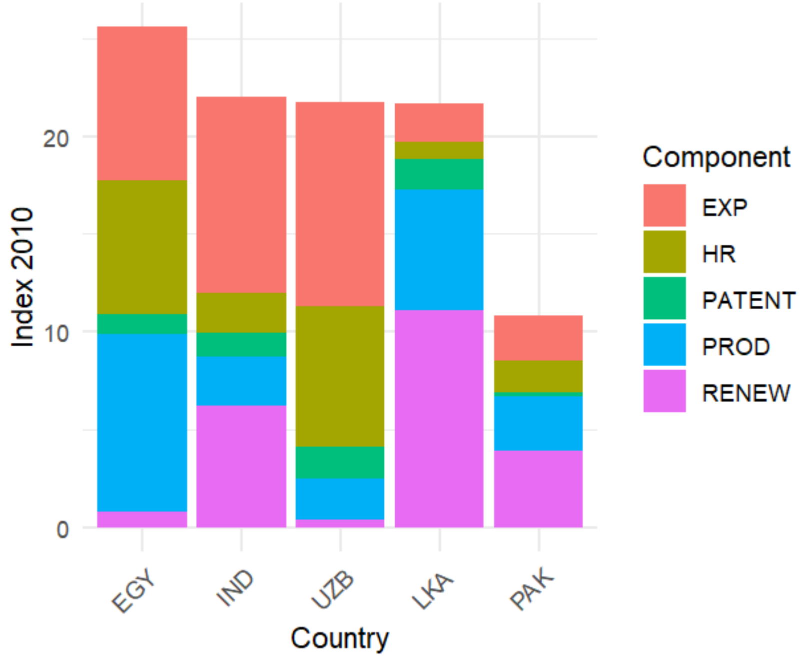
Graph 3



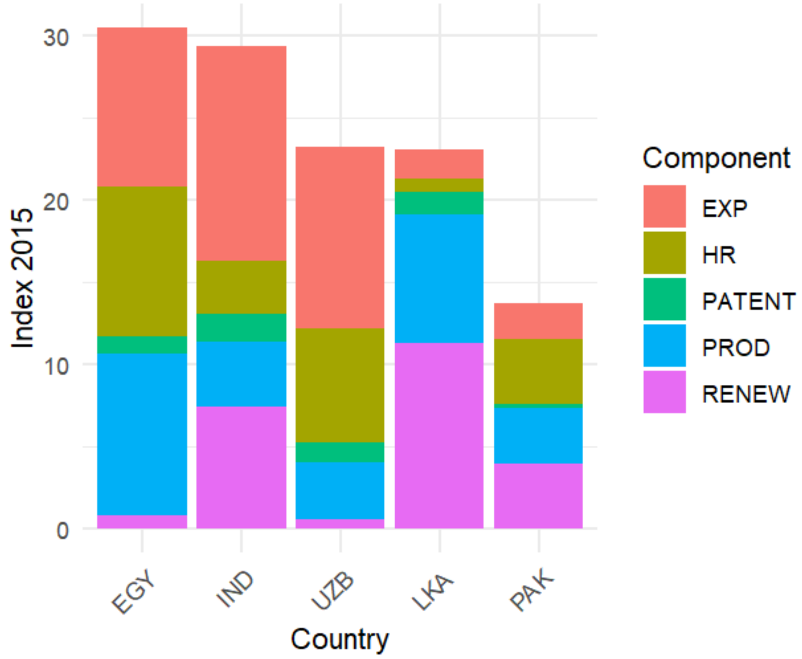
Graph 4



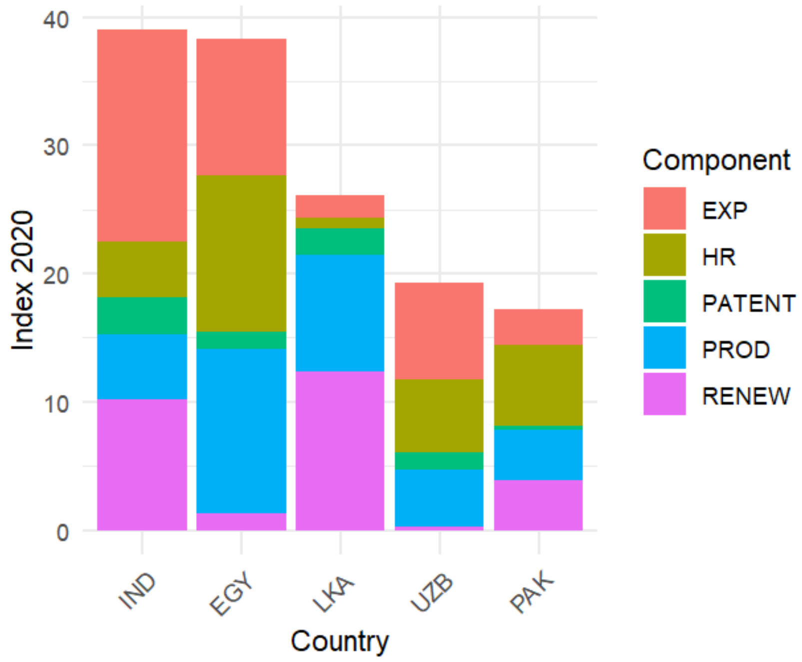
Graph 5



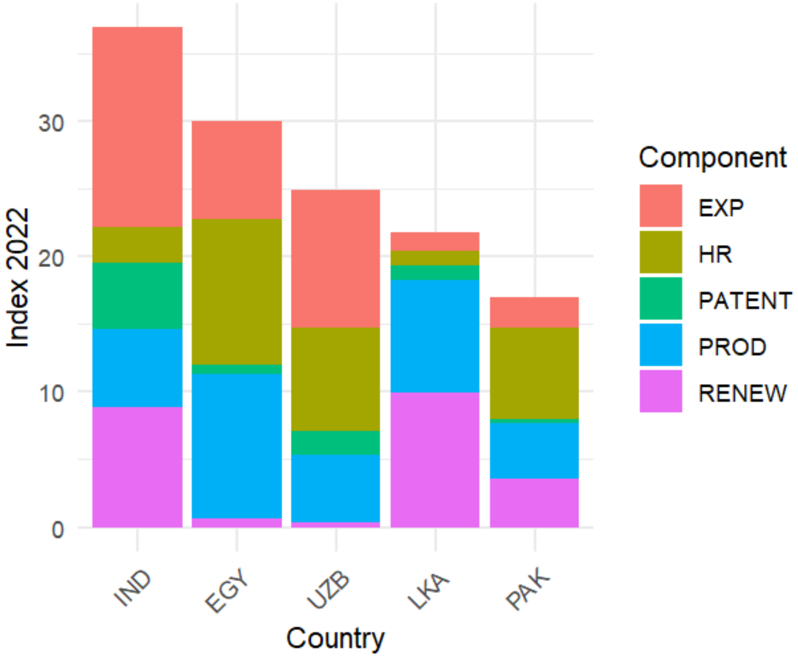
Graph 6



Graph 7



Graph 8



6.2. Policy Recommendations

Most of Pakistan's policies suffer from a lack of cohesion and poor alignment with broader economic goals, which diminishes their effectiveness. The most obvious example is the Digital Pakistan Policy 2018, which, although it had a great vision, was poorly funded and poorly implemented, therefore never realizing its full potential. This reflects a bigger problem in Pakistan, where the majority of policy initiatives never succeed due to a lack of resources and poor implementation. On the other hand, countries like India have succeeded in creating strong frameworks like the Intellectual Property Rights (IPR) Policy and Startup India initiatives. These efforts are well-funded and have clear implementation strategies, fostering innovation and entrepreneurship across sectors. Egypt's Vision 2030 serves as another example, aligning its policies across various sectors to ensure continuity and effective long-term outcomes. Egypt's policy coherence contrasts sharply with Pakistan's fragmented approach, where policies often lack coordination and fail to align with broader economic goals. One recommendation for Pakistan is to improve the funding and implementation of key policies, particularly those related to technology and innovation, to ensure they align with national economic objectives. Long-term planning and insulation from political changes are crucial for Pakistan, and a way to do this is to have a dedicated and autonomous body oversee the implementation of technology policies. In addition, a mechanism should be in place to track the progress of such policies to ensure that they stay on course despite political or institutional changes. Moreover, as there exists a causal link between the technology and economic growth , so the focus should be on development of such technologies should be the key focus that can actually translate to the better growth outcomes, through either increasing productivity or capital accumulation.

In addition to that, Pakistan has faced significant challenges in this area, with R&D investment accounting for less than 0.3% of GDP, one of the lowest rates globally. On the other hand, India has made significant strides in the area of research and development (R&D), allocating a higher percentage of its GDP towards R&D and leveraging both public and private sector investments. This commitment to innovation has translated into tangible outcomes, as India continues to generate higher levels of technological advancement and innovation outputs. Egypt, similarly, has focused on strengthening its technological capabilities through initiatives like the Industrial Modernization Program, which has enhanced its capacity for innovation and R&D. This limited investment, coupled with fragmented infrastructure, significantly undermines Pakistan's ability to compete effectively on a global scale. To address these challenges, Pakistan must prioritize increasing its R&D funding and invest in building the necessary infrastructure to support innovation. A concrete recommendation is to establish dedicated R&D funding bodies that focus on high-potential sectors, as well as to build partnerships with private industries to attract co-investment in R&D efforts. Further, creating an integrated R&D infrastructure could help maximize the impact of such investments. Ass allocating a higher percentage of GDP to R&D, similar to India and Egypt, is critical. Establishing research hubs, innovation parks, and technology clusters can create a conducive environment for sustained growth

The basis of India's approach to workforce readiness lies in structured programs like the Skill India Mission, which targets the dissemination of vocational training and digital skills among millions of youths. On its part, Egypt's Employment Strategy mainstreams workforce development in line with its broader economic goals and readies the workforce for the future of work, especially in technology and industrial sectors. The structured programs have indeed yielded positive results in terms of better workforce employability and productivity in both India and Egypt. In Pakistan, however, that is not very promising. Programs like the Prime Minister's Youth Skills Development Program have been rather small in scale and short-term in nature, leading to an absence of long-term impact. Such fragmented and short-term initiatives cannot satisfy labor market needs and result in a workforce incapable of driving innovation and economic growth. The main recommendation for Pakistan is to scale up skills development programs and align them with industry needs, especially in emerging sectors such as technology, digital skills, and renewable energy. In addition, a strong monitoring and evaluation system should be in place to ensure continuity and effectiveness of such programs.

Moreover, to bridge the gap between research and commercialization, Pakistan should establish a centralized National Technology Transfer Office (TTO). This office would facilitate collaboration between academia, research institutions, and industries to ensure that R&D outputs are transformed into market-ready innovations. The TTO should provide legal, financial, and logistical support for patent filings, licensing agreements, and technology deployment. Countries like Egypt have successfully implemented similar models under the Academy of Scientific Research and Technology, which has accelerated their innovation pipeline. Pakistan should create a Competitive Technology Fund (CTF) to incentivize innovation in high-tech sectors such as IT, renewable energy, and biotechnology. The fund should be performance-based, awarding grants or low-interest loans to companies and startups demonstrating high-impact technological advancements. A dedicated portion of this fund should focus on fostering regional innovation hubs, particularly in underdeveloped areas, to ensure inclusive growth. This approach aligns with India's Technology Development Fund (TDF), which has significantly boosted industry-led innovation.

In particular, Egypt and similar countries have made substantial achievements in the sphere of renewable energy through strategic projects like the Benban Solar Park, which drew massive international investments. Similarly, the National Solar Mission of India has shown the world how strategic subsidies and clarity in regulations can inspire private investments in renewable energy projects. These initiatives have positioned both countries as leaders in the renewable energy sector, leveraging their natural resources and attracting global investment. Pakistan, however, has struggled to replicate this success due to inefficiencies in its bureaucratic processes and inconsistent policy enforcement. The Alternative Energy Development Board in Pakistan has faced significant challenges in mobilizing investments and creating a conducive environment for renewable energy development. To improve Pakistan's renewable energy sector, a key recommendation is to streamline bureaucratic processes and establish clear, long-term energy policies. The government should also introduce specific incentives for private investment in projects and establish a transparent regulatory framework to attract both local and international investors. This would not only help meet energy needs but also contribute to broader economic growth and sustainability. Actively participating in international forums and fostering partnerships with technology leaders can bring resources and expertise to Pakistan. As aligning national policies with global goals like SDGs can attract foreign investments.

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APPENDICES

Appendix 1: Variables, Definitions and Data Sources

Table 1: Sub-Indictors of Tech Index, their Relevant Proxies, Definitions, and Sources

Variables	Weightage	Proxy	Definition	Source
EXP	20%	Medium & High-tech exports (% of manufactured exports)	It is the share of medium and high technology exports in total manufactured exports.	United Nations Industrial Development Organization (UNIDO), Competitive Industrial Performance (CIP) database
PROD	20%	Output per worker (GDP constant 2017 US$)	It is the total volume of outputs (GDP) produced per unit of labor measured in terms of the number of employed persons or hours worked during a day.	International Labor Organization (ILO - Modelled Estimates)
HR	20%	Researchers in R&D (per million people)	The number of researchers engaged in R&D is expressed as per million. Researchers are professionals who conduct research and improve or develop concepts, theories, models, techniques, instrumentation, or software for operational methods.	United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics
RE	20%	Share of modern renewables in total final energy consumption (% of total primary energy consumption)	Percentage of primary energy consumption coming from all modern renewable energy sources.	International Energy Agency (2022), World Energy Balances
PATENT	20%	Patent applications by residents	Number of patent applications filed by residents through patent cooperative treaty procedure or with a national patent office.	World Intellectual Property Organization (WIPO),
R&D	20%	R&D Expenditures (% of GDP)	Gross domestic expenditures on research and development (R&D), expressed as a percentage of GDP.	World Development Indicators

Table 2: Variables Used, their Proxies, Definitions, and Data Sources

Name of variable	**Nature of variable**	**Measurement**	**Proxies used**	**Definitions and Sources**
Tech Index	Independent variable	Technology advancement and technology adoption	Tech index (made up of sub-indicators made up of (Hi-tech exports, productivity spending, R&D spending, Human Resources in R&D, and renewable energy)	It measures the technological and scientific sophistication of the country. Source: Developed by Authors
Economic Growth	Dependent variable	Growth	GDP Growth (% change)	Annual percentage growth rate of GDP at market prices based on constant local currency. Source: World Development Indicators
Competition	Independent/ dependent variable	Competition in market	Competition intensity (no. of Industrial design applications, residents)	Applications to register an industrial design with a national or regional Intellectual Property (IP) offices and designations received by relevant offices through The Hague System. Source: World Development Indicators
Foreign Investment	Control Variable	Direct foreign investment.	Foreign direct investment, net inflows (BoP, current US$)	Cross-border investment associated with a resident in one economy having control or a significant degree of influence on the management of an enterprise that is resident in another economy. Source: World Development Indicators
Human capital development	Mediating variable	Representing the quality of access of human capital of a country	Human Capital Index– Pakistan	It measures the average achievements in a country in three basic dimensions of human development: a long and healthy life, access to knowledge and a decent standard of living. Source: United Nations Development Program Datasets

Appendix 2: Estimated Index -Results

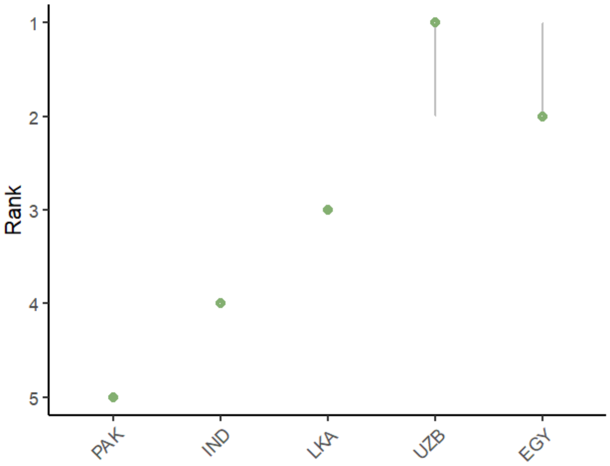
Table 3: Tech Index 1 (with Patents) and Tech Index 2 (R&D Expenditures) Scores

	Tech Index 1 (Patents)					Tech Index 2 (R&D Expenditures)				
Year	EGY	IND	LKA	PAK	UZB	EGY	IND	LKA	PAK	UZB
1990	18.22986	7.497947	9.021034	5.988409	21.64902	19.67049	14.87926	13.73139	9.948629	22.40563
1991	19.65817	8.437825	12.11352	6.098684	25.94909	23.3455	16.98031	18.09395	11.92647	21.10254
1992	17.99135	7.930896	9.008483	6.969346	21.87542	18.14116	15.76743	11.30992	6.938082	21.56073
1993	18.62082	8.456613	11.39574	7.667554	30.21318	20.05799	16.98231	14.68707	10.87322	23.85407
1994	19.31406	9.666333	11.49403	8.914886	24.71643	22.07754	19.01507	16.80432	14.807	22.08941
1995	21.38231	10.34576	12.63026	7.56727	23.59731	22.78271	20.01323	14.76243	11.23663	21.70747
1996	21.68223	12.09849	12.16205	7.549023	23.56592	24.17372	22.65681	15.4076	10.85999	20.61044
1997	20.40213	11.93156	15.69797	7.468751	22.64776	23.38751	22.31474	18.57798	11.42304	20.9241
1998	22.2841	11.55984	14.12721	8.450602	21.42119	24.63151	21.32822	17.91123	10.81679	20.33282
1999	23.12094	11.70505	16.46729	6.584323	23.16756	24.76695	21.84788	17.82957	8.722638	22.85455
2000	24.62217	11.72415	15.27946	7.2407	18.14697	26.7571	22.15627	16.87216	9.575405	17.97678
2001	22.76739	12.89251	17.17934	7.677131	18.79216	26.29791	24.01559	17.75425	11.28191	18.24228
2002	23.86995	13.34654	17.54662	7.382991	20.53865	27.43249	24.40371	17.29023	11.94195	19.60513
2003	23.72368	14.61227	17.50328	8.260453	23.67239	30.43535	25.7765	19.09263	12.51287	21.00172
2004	21.2906	15.77831	19.74284	8.170483	17.25118	27.45667	27.52311	21.81932	16.98682	19.43246
2005	20.827	16.91781	17.9351	7.83394	20.23163	25.62828	29.35957	17.31475	14.28311	22.16752
2006	22.41131	18.16829	18.00524	8.808317	16.8441	27.06881	30.48193	18.84612	17.03803	17.52183
2007	22.06188	19.11492	19.67556	10.53272	17.5797	26.86725	31.59869	19.25427	21.99499	18.16159
2008	24.84525	19.77186	19.8056	11.05577	16.61021	31.22317	33.11435	16.69104	21.07169	17.28368
2009	24.92203	20.76877	19.336	10.97089	19.50289	35.2879	33.91103	17.33856	21.03846	21.02956
2010	25.58427	22.02617	21.6882	10.82621	21.72335	35.03835	34.39555	19.22925	19.43793	19.80429
2011	26.76193	22.4653	21.60812	10.69388	18.82364	38.45141	34.84094	18.77774	19.50027	17.89293
2012	27.7042	23.6891	23.78243	10.5627	20.50327	38.86756	36.20252	19.20998	16.26993	20.18735
2013	27.95186	25.4182	24.06097	11.58732	20.5661	41.9466	37.73303	16.9068	19.75068	19.74718
2014	30.95289	27.22582	23.80357	12.53667	22.4334	45.2921	39.56612	16.15997	19.93467	20.96096
2015	30.41674	29.29842	23.03642	13.67911	23.22799	46.29338	42.21565	18.17425	21.59301	23.10643
2016	31.87502	30.67922	22.49415	13.68869	24.04536	46.41433	43.57899	18.46248	23.31457	23.46391
2017	32.07549	32.43164	25.41445	14.4817	24.71618	45.0016	45.05311	20.73313	22.14207	22.88286
2018	32.35646	34.41393	27.35749	15.9498	23.5765	46.46058	47.05636	21.58326	25.36988	19.30117
2019	37.22013	36.58471	25.31402	16.48151	22.33464	55.07148	48.47041	18.00104	22.52815	18.30382
2020	38.35275	38.98479	26.11969	17.21768	19.27026	59.21675	49.84774	20.23727	19.9455	17.55521
2021	33.49057	36.50192	25.64489	17.17489	23.08488	52.8102	47.42836	20.11396	22.19314	20.10144
2022	29.99533	36.89183	21.8065	16.99737	24.86165	52.16724	46.1407	17.7984	23.93661	23.01119

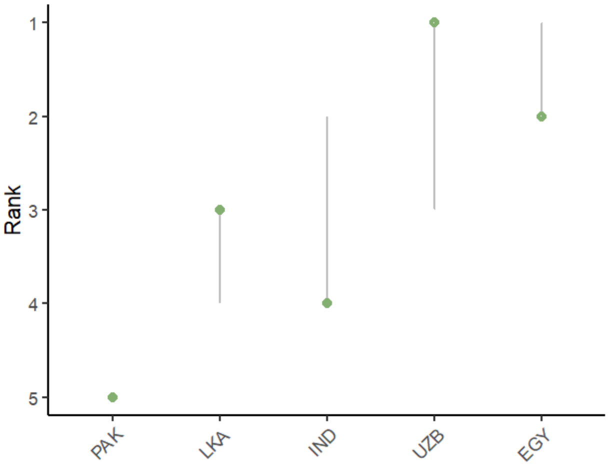
Appendix 3

Index I (Patents)

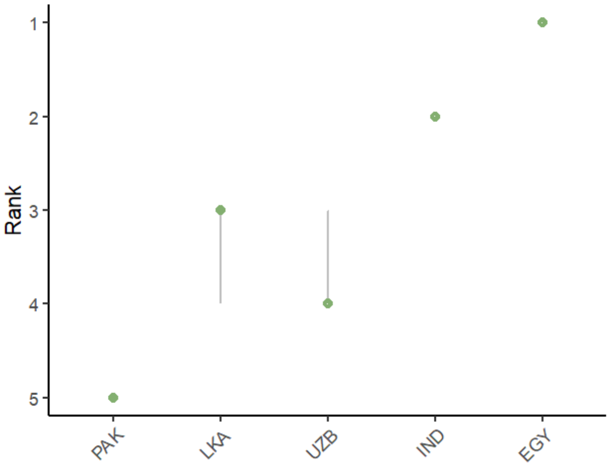
Uncertainty Analysis 2000



Uncertainty Analysis 2010

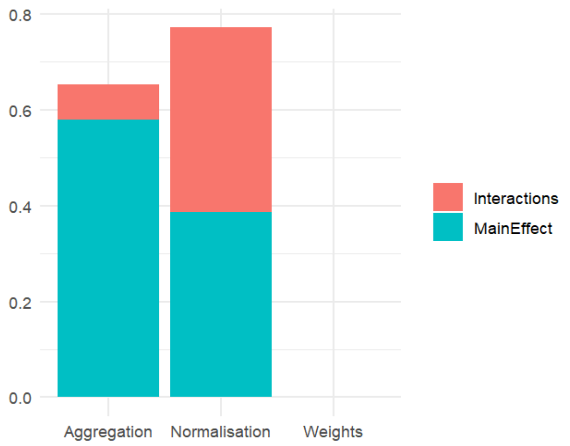


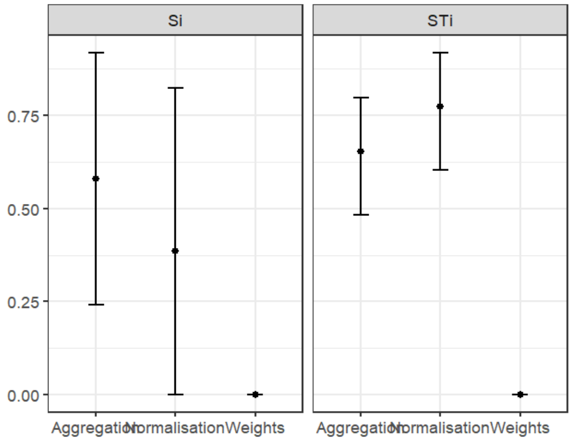
Uncertainty Analysis 2020



Index I (Patents)

Sensitivity Analysis 2000





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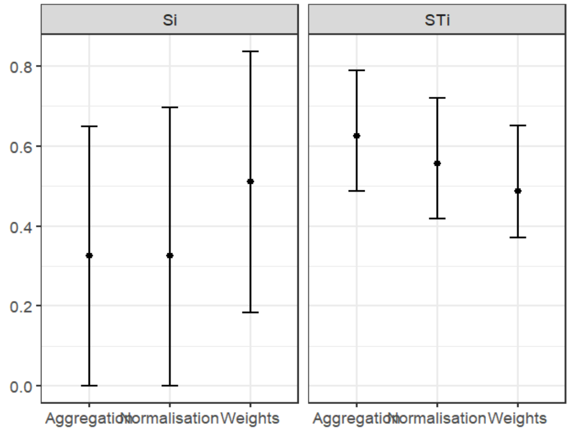
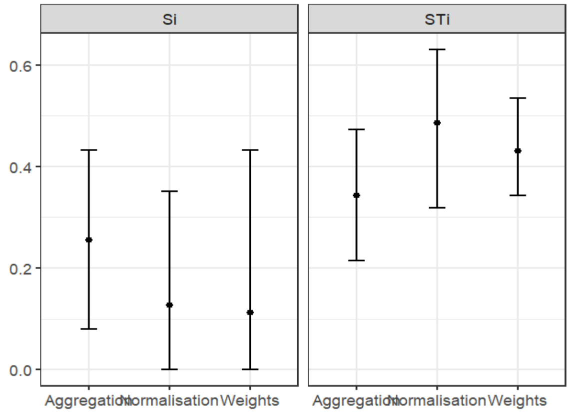
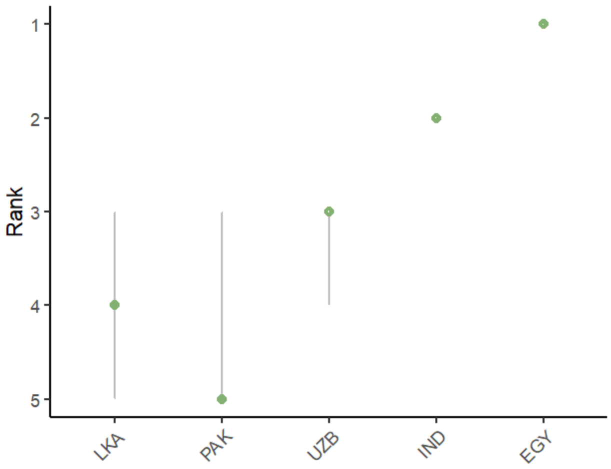


Sensitivity Analysis 2020



Index II (R&D Expenditures)

Uncertainty Analysis 2000



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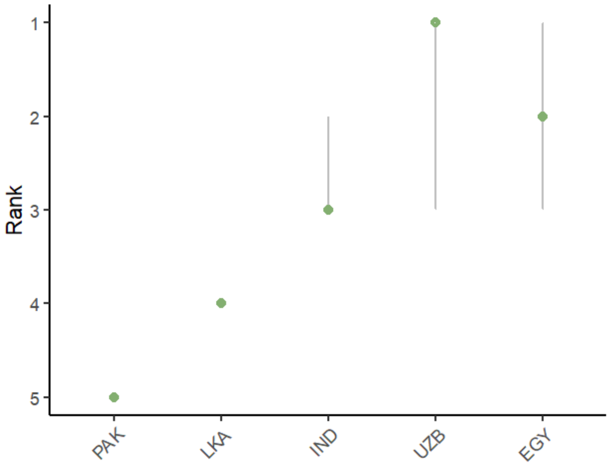
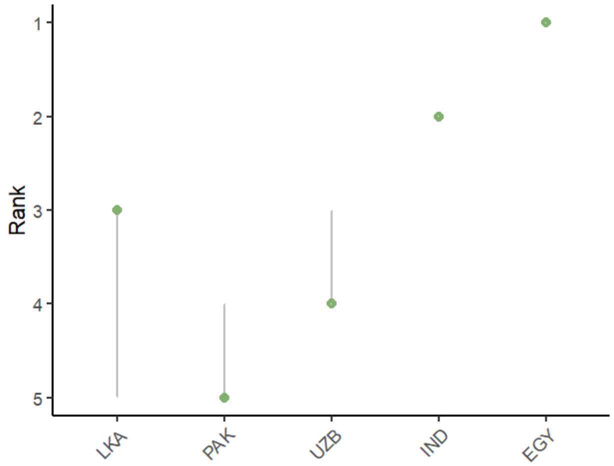
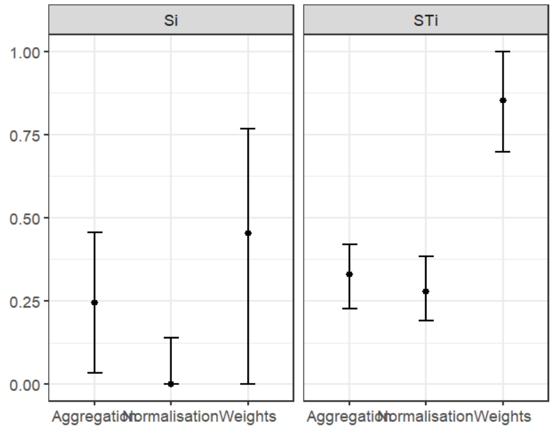


Uncertainty Analysis 2020

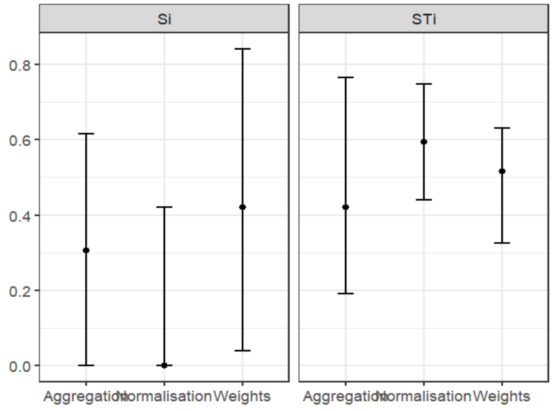


Index II (R&D Expenditures)

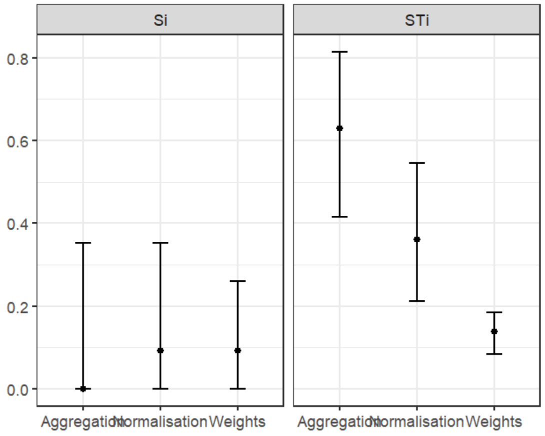
Sensitivity Analysis 2000



Sensitivity Analysis 2010



Sensitivity Analysis 2020



Appendix 4: Post Index Estimations

Table 4: Regression Estimates of Model 1 (Relationship between Technology Index and Competition)

Dependent Variable: COMP	OLS Estimates		2SLS Estimates	
	Coefficients	HAC Standard Errors	Coefficients	Standard Errors
TI	-0.0539*	0.027699	-0.0578*	0.030278
FDI	-0.0257	0.039846	-0.0697	0.086026
HDI	11.4919***	2.187234	11.5123***	2.116368
C	0.8206	0.748215	0.8997	0.712338
R-Squared	0.7664		0.7426	
F-Statistic	31.7231***		27.1989***	
Durbin-Wu-Hausman Endogeneity Test (FDI)	-		0.5601	
Cragg-Donald F-Stat.	-		44.8064	
Durbin-Watson Statistic	1.7657		1.7968	
BP Serial Correlation LM Stat.	5.9059*		3.8768	
BPG Heteroskedasticity Stat.	1.592		2.1307	
Jarque-Bera Normality Test	1.9686		1.0119	

Table 5: Regression Estimates of Model 2(Relationship between Economic Growth (GDP), Competition and Technology Index)

Dependent Variable: GDP	OLS Estimates		2SLS Estimates	
	Coefficients	HAC Standard Errors	Coefficients	HAC Standard Errors
COMP	7.86E-05	0.0089	0.0030	0.0251
FDI	-0.0018	0.0021	-0.0042	0.0041
TI	0.0036*	0.0018	0.0065***	0.0015
HDI	2.0663***	0.6642	2.3756***	0.5559
GDP(-1)	0.6989***	0.1124	0.6306***	0.0447
C	8.2643**	3.0892	10.1680***	1.2323
R-Squared	0.9982		0.9981	
F-Statistic	2988.07***		2823.12***	
Durbin-Wu-Hausman Endogeneity Test (FDI, TI)	-		2.9293	
Cragg-Donald F-Stat.	-		12.9024	
Durbin-Watson Stat.	1.6894		1.5519	
BP Serial Correlation LM Stat.	5.2453*		4.6277*	
BPG Heteroskedasticity Stat.	14.7828**		11.3706**	
Jarque-Bera Normality Test	0.2698		0.2151	

Table 6: Toda Yamamoto Causality Test

Direction	Chi-sq Statistic	Direction	Chi-sq Statistic
GDP ← TI	4.7031*	COMP ← GDP	0.0661
GDP ← FDI	3.3900	COMP ← TI	5.4927*
GDP ← HDI	4.9387*	COMP ← FDI	0.0694
GDP ← COMP	4.1091	COMP ← HDI	2.4688

FDI ← GDP	13.0955***	TI ← GDP	5.4822*
FDI ← TI	2.9161	TI ← FDI	0.3443
FDI ← HDI	4.8494*	TI ← HDI	2.9541
FDI ← COMP	7.0729**	TI ← COMP	0.6918
HDI ← GDP	1.0518	HDI ← FDI	0.9451
HDI ← TI	0.0497	HDI ← COMP	0.7576