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# Innovation Spillovers, Economic Growth, and the Role of Absorptive Ability

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## Abstract

*Research and Development (R&D) based economic sustainability is the current debate in endogenous growth framework to solve the problem of production inefficiency to achieve economic stability. The high Total Factor Productivity (TFP) growth can be attained through technological innovation, reverse engineering, 'learning by doing', artificial intelligence, and interaction of the researchers around the world. The adoption of foreign and domestic R&D innovation and its spillovers are relying on the willingness to opt, financial capital, and knowledge capital. The rationale of this study is to examine the importance of R&D spillovers for stable economic growth (EG) through the channel of knowledge diffusion in Pakistan. This research theme has been designed to investigate the proficiency of R&D diffusions in the absorptive capacity of the Pakistani labour force and the efficiency to progenitive utilization of R&D innovation. Quantitative analysis is carried out through the yearly time series data covering the period of 1972 to 2022. The Translog and Cobb Douglas production functions were employed to measure the TFP growth and Autoregressive Distributive Lagged (ARDL) Model was applied for empirical analysis. The quantitative analysis provided evidence of the presence of foreign and domestic R&D innovation spillovers and adoption in Pakistan with poor absorptive capacity. The study has indicated that foreign R&D spillovers have an affirmative role in TFP growth compared to domestic R&D. A great deal of policy wisdom has been generated, which directs that government should focus on sustainable policies related to local R&D, R&D spillovers with sufficient and sustainable R&D expenditures, their availability, and accessibility of innovation to boost the resource efficacy for higher TFP growth. The government should emphasise the implementation of extension services to educate workers by demonstrating the effectiveness of early adoption of innovation, innovative technology, and artificial intelligence (AI) to achieve sustainable productivity.*

**Keywords:** research and development spending, spillovers, knowledge capital, absorptive ability, TFP growth, time series analysis.

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## 1. Introduction

Research and Development (R&D) provides pivotal mechanism to transition the economy from resource-based to knowledge-based. In globalisation era, R&D becomes necessary for the achievement of sustainable economic growth, as only a knowledge-based economy can magnificently compete in the international market and achieve comparative advantages. Resource efficiency relies on level of R&D spending, internal knowledge, and labour capacity to absorb the innovation spillovers from across the world. The R&D spillover shocks are a long-term phenomenon that infiltrates the economy through various channels such as labour migration, international trade links, foreign direct investment (FDI), networking, international collaborations, and extension services. These channels are crucial in innovation diffusion, which is generated through R&D activities across borders, states, sectors, and industries. Once an economy achieved steady-state economic growth, further long-term economic growth potential can be fostered through continued engagement in R&D-based activities and its spillovers. This involves the dissemination of innovation across the state provinces, and industries and early adoption of innovative practices are as essential as spending in R&D based activities. Such initiatives contribute to attaining the potential level of output and competitiveness of a nation in the global market.

The economic growth measurement was initially introduced by Solow (1957), who adopted exogenous growth determinants. Subsequently, Jorgenson and Griliches (1967) elaborated the growth model and switched the conventional growth measurement process by incorporating labour and capital efficiency (quality) as crucial factors for higher economic output. Jorgenson and Griliches (1967) argued that the advancement of a country is not solely dependent on the quantity of physical capital, labour, and land, the quality of these inputs is equally essential in the production process to achieve the resource efficiency. In later developments, Griliches (1992) and Romer (1991) concluded that economic output hinges on R&D innovation, knowledge spillovers, and the ability to absorb innovation, reflecting labor efficiency or knowledge capital. For improving absorptive capacity, talent is an essential factor, as young researchers with innovative knowledge will endorse the exchange of ideas and collaboration that increased the R&D spillover process (Wang, 2015). On the foreign talent spillover may cause the crowding-out effect for internal/ existing talent, which is harmful to the internal innovation process (Agrawal et al., 2019) and inclusive growth process.

Initially, economists established fundamental connections between R&D spillovers and productivity by treating technological innovation as an exogenous variable. The importance of R&D gained as Griliches (1973) incorporated the R&D spillovers as an endogenous determinant of economic output. Within the framework of production function, the significance of R&D innovation has grown over time through novel-orientated studies on endogenous growth theories that positioned the R&D innovation as influential determinants of economic output (Aghion & Howitt, 1990). Furthermore, Griliches (1992) emphasised on R&D spillovers as a primary driver of economic output, fostering innovation and spillover shocks to cost-efficient and market-compatible products that enables firm or economy to secure comparative advantages. New growth theories heighten the role of R&D spillovers as catalysts for technological progress and innovation adoption in economic growth (Romer, 1990; Grossman & Helpman, 1991).

## *1.1 R&D Spillovers and Economic Growth*

Technological innovation facilitates the mapping of inputs to outputs by improving product efficiency. R&D contributes distinctive and first innovative knowledge, which often entails strong complementary inputs, such as AI, tools, materials, and energy sources. Technological spillover is the utilisation of R&D generated knowledge spillover to gain the higher productivity with fewer resources. Empirical and theoretical studies that examine R&D models consistently indicate that R&D spillovers exert a substantial influence on the production performance of the manufacturing, agriculture and service sectors, minimizing the environmental damage both in developed and developing countries (Coe & Helpman, 1995; Lee, 2013; Liu et al., 2015; Maria & Smulders, 2017).Innovation spillovers are fundamental drivers for enhancing productivity, catalysing innovation, facilitating the 'learning-by-doing' process, and enhancing the value addition process both in agriculture and manufacturing sectors. Furthermore, R&D spillovers worked as an instrument to achieve the potential level of output to sustain long-term economic development. International trade emerges as a key factor for knowledge spillovers and innovation adoption, which is helpful in introducing efficient product varieties across borders. International trade in technological products increase market size through innovative commodity varieties and trade openness in R&D based products, which plays a fundamental role for introducing novel products, providing ways to access technical knowledge and mitigates the cost of innovation (Rivera & Romer, 1991; Usman et al., 2021).

R&D spending provides an imperative for obsolescence, surviving competition, and navigating waves of disruption. Engaging in R&D activities provides distinct advantages in terms of innovation spillovers and absorptive capacity, weather at national level, corporate level, or individual researcher dedicated to exceptional efforts in unique knowledge and product development. The economic impact of R&D spending manifests in progressive ways through the manufacturing and agriculture sector, which improves the knowledge efficiency of the labour force (Coe et al., 2009; Usman et al., 2021). Raza and Siddiqui (2014) hypothesise that spending on R&D enhance the production process in the economy, brings innovative technology and techniques in production, and provides efficient goods and services, allowing the economy to produce the higher value goods and services. In the context of economic development, innovative technologies generated through R&D initiatives are characterised by increased durability, capability, and power in high-intensity production of market-compatible products, which improve the living standard in the economy and the economic development process. Moreover, the positive spillover of R&D generates innovative knowledge; benefits can emanate from imported goods and services, which developed by trade partners, also enhance the productivity growth of the host country. In addition, Ho et al. (2009) argued that more open countries gain greater productivity from external R&D expenditure compared to economies with lower level of openness, demonstrating the significance of R&D spending that transcends national borders, fostering innovation, improving productivity, and contributing to overall economic development.

The empirical results of Liu et al. (2016) suggests that the contribution of R&D spillover, both from foreign and domestic sources, significantly influences economic growth, which is directed to enhance the development and living standard of the economy. In addition, Gorkey (2014) delves into the long-term repercussions of technological spillover on economic and environmental conditions, and the findings reveled that R&D spillovers play a pivotal role in improving domestic output while minimizing environmental damages. The interdependence of a host country's R&D spillover and innovation capacity is dependent on various factors, such as innovative thinking, knowledge capital, "learning by doing", learning through experiences, and the absorptive capacity for foreign knowledge (Castle et al., 2014; Richard et al., 2023). Furthermore, comparative advantage and profit margin through investment in R&D spillover improve the strategic partnership between research institute and domestic firms, which accelerates the way of innovative thinking and domestic R&D spillovers process. Such collaborations contribute to the creation of unique new products in competitive markets, subsequently leading to increased customer satisfaction, improved performance, and a comparative advantage in the sale of products globally.

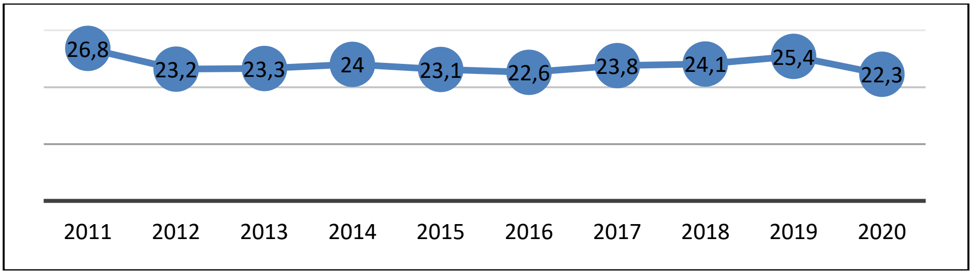
Inclusive and exclusive R&D spillover-driven growth plays a pivotal role in shaping modernisation and societal development. However, it is important to note that not all forms of growth can be attributed to technological advancement, improved allocation, and scale economies. Economic development resulting from R&D spillovers brings knowledge acquisition about significant improvement in living standards, life expectancy, quality of essential services and mitigate adverse poverty shocks. R&D spillovers benefitted a selected group of original, driven, and skilled individuals who push technological progress. Successive technology creates new demands, and thus generates further interest in endogenous R&D activities (Sulehri et al., 2023). On the contrary, the development of novel practices can be spearheaded by highly skilled engineers, scientists, and researchers who have immediate access to pertinent propositional knowledge; ingenuity serves as a driving force behind continuous progress (Xu & Khan, 2023).

Economic theories propose two primary drivers of economic growth in the current situation, such as accumulation of R&D and human capital development (Asim & Sorooshian, 2021). Both human capital and R&D play an incremental role in productivity in all sector of the economy. Research fosters knowledge creation, while R&D serves as the mechanism through which researchers generate new knowledge, formula, technology, technique, products or services both nationally or internationally (Usman et al., 2021; Stads et al., 2015). R&D based innovation is utilised individually or offered at the marketplace to produce efficient and market-orientated goods and services to earn higher profits. Innovative technology allows producers to maintain output with fewer resources or increase output with the available resource (cost minimisation or profit maximization process). Undoubtedly, reliable research and timely adoption have dynamically contributed to the economy generate tangible benefits, promoting stable economic growth, and coping risks aimed at rapid economic integration. The R&D process at the firm or country level typically encompasses seven fundamental stages: knowledge generation, idea screening, development and testing (including patenting), strategy formulation, product development implementation, market testing based on practical applications, and finally, commercialisation or the sale of innovative patents (Sulehri et al., 2023).

### *1.2 Pakistan's Innovation Index*

The innovation index captured national elements that measured the domestic innovation activities, consists of five input pillars and two output pillars. The input elements are human capital and research, research institutions, infrastructure, sophisticated business, and market, while the output pillars are unique new product and knowledge-based outputs (Global Innovation Index, 2020). The average value of Pakistan's innovation index from 2011 to 2020 is 23.85 points, the maximum value of the innovation index is 26.8 during 2011, and the minimum value is 22.3 during 2020 (Figure 1). In the global innovation index ranking, Pakistan is ranked 108 among 131 countries (Global Innovation Index, 2020).

**Figure 1. Pakistan Innovation Index**




*Source:* Global Innovation Index, 2020.

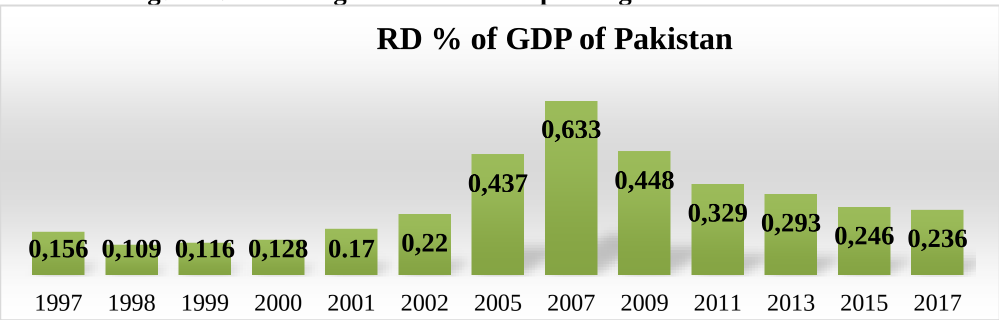
### *1.3 R&D Expenditures of Pakistan*

In Pakistan, the public sector has the utmost proportion of expenditures allocated to R&D through investments in higher education, while universities are considered the main research institutions. Higher education R&D expenditures in Pakistan do not produce significant effects on the creation of new knowledge (Khan & Khattak, 2014). R&D spendings and EG have a two-way relationship, as economic growth increases, it leads to increases the R&D expenditures. Conversely, the rise in R&D synthesis leads to enhanced EG. Similarly, Ildırar et al. (2016) found the bidirectional causality between economic growth and R&D spending. Spending on

R&D capital highlight the country's priority for science and technology, innovation, and knowledge spillover, which leads to economic development in the long run.

R&D spending of a country, firm or individual efforts to design, develop and enhances its unique services, products, technology, formula or processes. R&D spending as a proportion of GDP of Pakistan includes both current and capital expenditures, which comprises four main dimensions such as business enterprise expenditures for innovation, government expenditure on innovation, higher education spending, and contributions from private non-profit sector expenditures. In Pakistan, the percentage share of R&D spending is shown in Figure 2, which highlights that in 2007 the % share of R&D spending was high and was 0.63 percent of GDP of Pakistan. The government R&D spending as a percentage GDP is not satisfactory as much as required for the internal research and innovation process. In 2017, the percentage of R&D spending of GDP was 0.236 percent compared to 0.246 percent in the previous period. R&D expenditures as percentage GDP graph shape look like normality curve and R&D expenditures were at peak during 2007. The lowest R&D expenditures were during 1998, with a percentage share of GDP of 0.109 percent. The R&D structure in Pakistan is not well established and government, firms, individuals, or researchers are not familiar with the importance of R&D innovation to acquire competitive advantage in science and technology and positive shocks for country development.

**Figure 2. Percentage share of R&D spending in GDP of Pakistan**




*Source:* World Development Indicators, 2020.

## *1.4 Problem Statement*

Drawing insights from both international and domestic literature, this study concludes that there remains ambiguity regarding the contribution of R&D innovation to the economic growth of a country. A comprehensive review of studies suggested that R&D diffusion produces positive externalities and technological transformation, labour migration, and knowledge shocks are the key determinants to achieve long-term economic growth (Griliches, 1992; Keller, 2021; Rismawan et al., 2021). On the contrary, many studies argue that R&D spillovers produce negative externalities, such as increased unemployment, increased comparative cost of the industry, increased income inequality, elevated water and air pollution, reduced availability of organic food, and decreased domestic productivity (Aitken &

Harrison, 1999; Ahmad et al., 2020; Lucking et al., 2018; Adetutu & Ajayi, 2020). Based on diverse literature, this study identifies key questions that have not been adequately addressed in the context of Pakistan. What is the quantitative narrative of the spillovers of R&D spillovers for the economic success of Pakistan? What role do R&D and its spillovers play in the economic growth of Pakistan? Does absorptive ability exist within the Pakistani labor force? Whether the human capital efficiency of innovation adoption contributes to innovation spillover across the country? Does domestic R&D spillover have a crucial influence in promoting EG compared to foreign R&D spillover? By addressing these questions, the study aims to increase the comprehension of the nuanced relationship between R&D spillovers, innovation, and productivity growth in the context of Pakistan.

This research significantly adds to the body of knowledge already available on R&D and its spillovers in Pakistan in several ways. First, it represents one of the initial efforts to systematically investigate R&D spillovers on economic success in Pakistan. Second, the study explores the mechanism through which R&D spillovers are evident, emphasising both domestic and foreign sources, such as trade and FDI as an important channel for R&D spillover dynamics. Third, the research employs robust methodologies to calculate the TFP adopting both the Translog and Cobb Douglas production functions. Fourth, the existing literature regarding R&D spillovers predominantly adopted cross-section or panel data, like cross-country or regions, this research pioneers a time-series analysis approach for a more nuanced and carried analysis for country specific. Additionally, the investigation not only focusses on R&D spillover tools, but also incorporates an assessment of laborer absorptive capacity in Pakistan. Fifth, the existing literature on the adoption of technology in Pakistan (Akhtar & Pirzada, 2014; Ali, 2013; Chavas & Nauges, 2020; Raza et al., 2017; Wang et al., 2020), a limited study focused on examining the impacts of manufacturing and agri-inputs through FDI. This research stands out as a unique contribution, systematically measuring TFP growth and investigating the intricate association between opting for R&D and absorptive capacity in influencing economic growth. By addressing these gaps, this study significantly advances our understanding of the complex dynamics surrounding R&D diffusions and its contribution to productivity growth in Pakistan.

### *1.5 Research Objectives*

R&D innovation bring novel technologies, technique, formula, and knowledge to obtain higher development, efficient, unique, and market-orientated products, which significantly contribute to the steady state level of EG. Moreover, the adoption and absorption of new technology, knowledge, or research play an essential contribution to enrich the R&D spillovers for sustainable long-term economic growth. The primary focus of this research is to investigate the influence of the spillover of R&D spillover on EG in Pakistan to explore the absorptive capacity of the workforce in Pakistan. The key objectives of the research are as follows.

- Investigate the contribution of R&D spillovers in fostering stable TFP growth in Pakistan through the channels of innovation diffusion.

- Assess the absorptive capacity of the Pakistani workforce in relation to the adoption of innovation and the adaptation of new knowledge spillovers.
- Quantify the effect of both R&D spillovers form domestic and foreign R&D spillovers on the economic performance of Pakistan.

## 2 Materials and Methods

Research in technological innovation is an important driving force in economic success and economic integration across boundaries. Neoclassical economics focused on technological innovation as exogenous and focused on factor accumulation (such as labour, capital, and land) as a source of economic output (Solow, 1957; Cass, 1965; Koopmans, 1965). Standardised technology modernised the country and provided an alternative competing system for development, and coalitions with other stakeholders to innovate. Endogenous economic growth models integrate technological innovation and consider knowledge and R&D spillovers within the growth model (Romer, 1990; Grossman & Helpman, 1991). The total factor productivity and economic output are dependent on domestic R&D and its spillover shocks from foreign sources.

R&D spillovers have similar process that benefits trading partners (Griliches, 1998) While knowledge diffusion has causal roots in non-competitiveness and exclusive technology (Romer, 1991). Knowledge spillover extends up to 300 km (Bottazzi & Peri, 2007). However, today globalisation ear, transportation advancement, communication, and IT have amplified spillover impacts across the globe if the host country is as efficient in absorptive ability of innovative knowledge. Typically, the knowledge generation process spreads through face-to-face interactions among researchers, policymakers, and field workers. Absorptive capacity creates hurdles in disseminating knowledge in distant areas, particularly for unskilled laborers. The effectiveness of knowledge spillover is reliant on country absorptive ability, reduces the innovation cost, and transmission cost, time horizon (Hauser et al., 2007). R&D spillovers are positive associated with the growth of TFP, the output elasticity was between 10 and 30% for firms operating within the same industry. Both government and company R&D spending contributes positively to TFP growth. The growth of TFP depends on the size and distribution of funds for R&D and innovation activities (Bronzini & Iachini, 2014). Furthermore, Guellec et al. (2001) have found an inverse synergy among defence related R&D compared to civilian R&D spending on TFP. Similarly, Ho et al. (2009) found a protracted elasticity of the R&D spending contribution to TFP growth to be 0.091 in the case of Singapore. Both R&D and TFP growth are complementary goods (Cin et al., 2017; Czarnitzki & Hussinger, 2018; Bye et al., 2019).

**Table 1. Theoretical revolution in exogenous growth models and R&D innovation**

| | | |
|---|---|---|
| **Creative Destruction** | | |
| **Schumpeter (1934)** | "Process of industrial transformation that continuously revolutionises the economic structure, destroying the old one, continuously creating a new one" | |
| **Revaluation in Exogenous Growth Model** | | |
| **Harrod–Domar Model (1939, 1942)** | Physical Labour | Additional labour with fixed capital ratio increases the productivity (increase in population rise the economic growth). |
| **Solow and Swan (1956)** | Physical Capital | The increase in physical capital accumulation increases the productivity (keeping fixed labour). |
| **Porter's Diamond (1965)** | Diamond Model | Government should act as catalysts and pursue the policy to achieve competitive advantages in international market. Advantages can be gained through factor proficiency, international demand, and firm strategy, structure, and rivalry. |
| **Griliches (1967)** | Quality of Input Resource | Highlights the efficiency and quality of labour and capital as a key to economic success. |
| **Revaluation in Endogenous Growth Model** | | |
| **Griliches (1973, 1992,1998), Grossman and Helpman (1991); Aghion and Howitt (1990);** | R&D spending and Technological innovation | Considered the R&D capital and technological innovation in endogenous framework. |
| **Romer (1990); Lucas-Uzawa (1988)** | Human Capital Efficiency | Human capital is as important for economic success as physical capital and labour. Long-run economic growth as dependent on knowledge capital that creates innovation spillovers. The Lucas model focused on formal education rather than learning-by-doing. |
| **Romer (1990); Romer (1991); Coe and Helpman (1995); Coe et al. (2009)** | Efficiency of R&D capital with Human Capital | The efficiency of R&D spillovers from domestic and foreign sources is considered in the endogenous factors in growth model. Investment in human capital is key to technological innovation and accelerate the spillover process. |
| **Aghion and Howitt (1996); Aghion and Caroli (1999); Howitt (2007)** | Green R&D Innovation | Innovation competition and R&D based green growth based on R&D is needed for further economic output. |
| **Modern Approach** | | |
| **Solow (2007); Barro (2015); Nordhaus (2018); Pylypenko et al. (2023)** | R&D Efficiency, Environmental Capital, and Institutional Framework, Social Capital | Institutional framework and policies provide protection to R&D, knowledge capital, environment sustainability, and social capital are important factor of economic growth. If one institution is not working efficiently, it affects all other integrated institutions and creates economic discrepancy. |

Source: author's own.

## *2.1 Data Framework*

This research examined the time series analysis on R&D spillover effectiveness from both domestic and foreign spillovers shocks TFP growth in Pakistan. The spillover effects R&D is examined through different instruments by acquiring the yearly data covering 1972 to 2022. Data related to economic performance and R&D spillovers were gathered from various national and international sources, such as various issues of Pakistan Bureau of Statistics (PBS), Pakistan Economic Survey, State Bank of Pakistan, Pakistan Ministry of Finance, Penn World Table 10.01, and World Development Indicators (WDI).

## *2.2 Analytical Framework*

The R&D expenditures and early adoption of innovation make a valuable contribution to economic production of the economy. R&D involves innovation, new technology, and unique product varieties to earn comparative advantages and global exchange export revenue. R&D play a vital role in influencing the education, knowledge, financial capacity, management skills, practical experience, readiness to choose novelty and capacity to absorb the new knowledge of firms, farmers, and individual's, thereby shaping their ability to adopt innovation earlier. The results indicated that R&D spending rate of return on R&D spending is higher and investment for innovative technology, product varieties, new seeds and fertilisers provide a significantly higher output both from manufacturing and agriculture (Chandio et al., 2021). List of methods are available for calculating the TFP growth, including indexing approach, Cobb Douglas production function, stochastic frontier, OLS, etc. Such methods are not relevant in this research because of data limitations (Sharif et al., 2021).

For Pakistan's economy, the TFP growth is calculated using the Cobb Douglas production function due to a constraint. Furthermore, the TFP growth is calculated at cumulative level through the Cobb-Douglas production function, which makes sense for estimating the TFP growth using traditional yearly time-series data that is dependent on capital and labour inputs. The assumption of constant return to scale was included in the Cobb Douglas production function in the respective of capital and labour (Coe & Helpman, 1995; Coe et al., 2009). The Translog and Cobb Douglas production functions were applied to measure TFP growth by adopting the Hicks neutral (Constantin et al., 2021).

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} \qquad (1)$$

In Model 1, output is denoted by $Y_t$, labour by $L_t$, capital stock by $K_t$, and $A_t$ is the TFP (Salim & Islam, 2010). Whereas, 't' shows time series, while α and β are representing the elasticities of both the capital stock and labor force. Tanking logarithm on both in equation 1, and converting it into input-output model, equation 3 was used to calculate the TFP growth. By applying the properties of logarithm, the final equation for measurement of TFP growth is as follows:

$$TFP_t = Y_t / K_t^{\alpha} L_t^{\beta} \quad (2)$$

$$\ln TFP_t = \ln Y_t - (\alpha \ln K_t + \beta \ln L_t) \quad (3)$$

By adopting the 3 equations, $TFP_t$ growth was calculated, where inputs are capital and labour. Furthermore, the net capital stock $K_t$ was measured for the economy, and the perpetual inventory method was adopted as given in Equation 4 (Coe et al., 2009; Lapple et al., 2016).

### *2.3 Net Capital Stock*

Gross capital formation, which is measured through the entire amount of capital expenditure made by the economy, is the increase in the stock of capital. Net investment in the economy is defined as gross capital formation after inflationary effects and depreciation are subtracted. The depreciation is referred as the difference between gross capital formation and fixed capital consumption, which is the net capital stock. The wear and tear costs incurred by fixed capital to keep capital stock in its initial state are referred to as the depreciation rate. According to Kuo and Yang (2008), the average life of machinery (capital equipment) is used to calculate depreciation.

The net capital stock is determined using the Perpetual Inventory Methodology (PIM) technique, which is based on Griliches (1979) and Barro & Sala-i-Martin (2004). This method includes an approximation of the growth rate, the depreciation, and the initial capital stock. The growth rate for the preceding period is taken to be the current capital growth rate (Sharif et al., 2021). The following are estimated formulations:

$$K_{t+1} = I_t + (1 - d)K_t \quad (4)$$

In equation 4, "t" stands for time, "$K_{t+1}$" for net capital stock, "d" for the depreciation rate, and $I_t$ for gross capital stock. Although the initial capital formation was determined using gross fixed capital formation, the study's primary focus was on quantifying net capital stock. The following is the methodology for calculating the beginning capital:

$$I_o = \frac{I_i}{g_i + d} \quad (5)$$

In equation 5, $I_o$ starting level gross capital stock and $g_i$ is capital formation growth rate. To measure capital stock, GDP growth from the previous era was used as a proxy (Sharif et al., 2021) of growth in capital formation. To calculate the net capital stock, the depreciation data are taken from Penn World Table 10.01. It is necessary to interpret the growth of capital stock as "g" as an average growth of capital stock over the sample range.

## 2.4 Model for R&D Capital and Economic Growth

Comprehensive research has been conducted in the literature relevant to economic performance and the role of R&D spillover in the international forum. Würtenberger et al. (2012) highlights the issue related to R&D spillover and its role in economic growth and argued that technological spillover is key factor to boost the long-run economic growth. Available studies adopted various mechanisms for capacity to absorb innovation, whereas few studies have focused on educational expenditures and human capital (Criscuolo & Narula, 2008; Keller, 2004), while other focus on R&D investment and emphasized on new knowledge adoption (Wang et al., 2010), and technological infrastructure (Chuang & Hsu, 2004). The list of researches explained the ability in form of national social and innovative culture, infrastructure, orientation, and government inducement for the adoption of new knowledge. The production function in the form of Cobb-Douglas is as follows

$$Y_t = TFP_t L_t^{\alpha} K_t^{\beta} \tag{6}$$

In notation 6, $Y_t$ is the productivity output, while $TFP_t, L_t^{\alpha}\ and\ K_t^{\beta}$ are total factor productivity, labor force and capital stock, respectively. Therefore, the TFP is dependent on the knowledge spillover ($A_t$) Human Capital Index (HC) and R&D activities (RD) both domestic and foreign.

$$TFP_t = A_t HC_t^{\gamma} RD_t^{d} RD_t^{f} \tag{7}$$

The knowledge spillover is dependent on technological changes (TC) and fixed technology (FT).

$$A_t = TC_t FT_t \tag{8}$$

For substituting the value of $A_t$ and $TFP_t$ the equations 6 and 7 become

$$Y_t = TC_t FE_t HC_t^{\gamma} RD_t^{f} RD_t^{d} L_t^{\alpha} K_t^{\beta} \tag{9}$$

$$TFP_t = TC_t FE_t HC_t^{\gamma} RD_t^{f} RD_t^{d} \tag{10}$$

To quantify the role of R&D spillover and its impact on economic growth, this research takes the log and adds the intercept and residual terms in Equations 9 and 10. This gives the final estimated model in the form of economic growth and TFP growth. The effects of FDI inflows are productivity-driven and dominant on the growth of the TFP per worker, so the FDI inflows privileges are subordinate to the host country's absorptive capacity. To sustain and long-run economic growth, countries require knowledge-driven, quality institutions and skilled-based human capital (Ahmed & Kialashaki, 2019; Le et al., 2021). The transformed growth is as follows.

$$lnY_t = \beta_0 + \beta_1 lnTC_t + \beta_2 lnFT_t + \beta_3 lnHC_t + \beta_4 RD_t^{f} + \beta_5 RD_t^{d} + \beta_6 lnL_t + \beta_7 lnK_t + \beta_8 lnHC_t * RD_t^{f} + \epsilon_t \tag{11}$$

Currently, researchers are more enthusiastic about multidisciplinary and multidimensional knowledge skills, which increase absorptive ability as well as converted economy from resource-based to knowledge-based. Collaboration among stakeholders (like universities, research institutions, and industries) can improve absorptive ability, which plays a mediating role in innovative capabilities and industrial performance (Asplund & Bengtsson, 2020; Zhai et al., 2018). The final estimated model is as follows

$$lnTFP_t = \beta_0 + \beta_1 lnTC_t + \beta_2 lnFT_t + \beta_3 lnHC_t + \beta_4 RD_t^f + \beta_5 RD_t^d + \beta_6 lnL_t + \beta_7 lnK_t + \beta_8 lnHC_t * RD_t^f + \epsilon_t \quad (12)$$

The estimated model of R&D spillovers and impact of absorptive capacity on output growth in Pakistan in the form of ARDL is as follows.

$$\Delta\ln(\mathrm{TFP})_t = \beta_0 + \sum_{t=1}^{n} \beta_1 \Delta\ln(\mathrm{EMP})_{t-1} + \sum_{t=1}^{n} \beta_2 \Delta\ln(\mathrm{HC})_{t-1} + \sum_{t=1}^{n} \beta_3 \Delta\ln(\mathrm{ECI})_{t-1} + \sum_{t=1}^{n} \beta_4 \Delta\ln(\mathrm{TOP})_{t-1} + \sum_{t=1}^{n} \beta_5 \Delta\ln(\mathrm{Tech\_Imp})_{t-1} + \sum_{t=1}^{n} \beta_6 \Delta\ln(\mathrm{UT})_{t-1} + \sum_{t=1}^{n} \beta_7 \Delta\ln(\mathrm{Tech\_Exp})_{t-1} + \sum_{t=1}^{n} \beta_8 \Delta\ln(\mathrm{Uni})_{t-1} + + \sum_{t=1}^{n} \beta_9 \Delta\ln(\mathrm{RD\_OECD})_{t-1} + \sum_{t=1}^{n} \beta_{10} \Delta\ln(\mathrm{RD\_USA})_{t-1} + \sum_{t=1}^{n} \beta_{11} \Delta\ln(\mathrm{RD\_China})_{t-1} + \sum_{t=1}^{n} \beta_{12} \Delta\ln(\mathrm{R}\&D\_W)_{t-1} + \sum_{t=1}^{n} \gamma_1 \ln(\mathrm{EMP})_{t-1} + \sum_{t=1}^{n} \gamma_2 \ln(\mathrm{HC})_{t-1} + \sum_{t=1}^{n} \gamma_3 \ln(\mathrm{ECI})_{t-1} + \sum_{t=1}^{n} \gamma_4 \ln(\mathrm{TOP})_{t-1} + \sum_{t=1}^{n} \gamma_5 \ln(\mathrm{Tech\_Imp})_{t-1} + \sum_{t=1}^{n} \gamma_6 \ln(\mathrm{UT})_{t-1} + \sum_{t=1}^{n} \gamma_7 \ln(\mathrm{Tech\_Exp})_{t-1} + \sum_{t=1}^{n} \gamma_8 \ln(\mathrm{Uni})_{t-1} + + \sum_{t=1}^{n} \gamma_9 \ln(\mathrm{RD\_OECD})_{t-1} + \sum_{t=1}^{n} \gamma_{10} \ln(\mathrm{RD\_USA})_{t-1} + \sum_{t=1}^{n} \gamma_{11} \ln(\mathrm{RD\_China})_{t-1} + \sum_{t=1}^{n} \gamma_{12} \ln(\mathrm{R}\&D\_W)_{t-1} + \sum_{t=1}^{n} \delta_1 \ln(\mathrm{HC} * \mathrm{FDI})_{t-1} + \delta_2 \ln(\mathrm{HC} * \mathrm{TOP})_{t-1} + \delta_3 \ln(\mathrm{HC} * \mathrm{RD\_Tech\_Imp})_{t-1} + \delta_4 \ln(\mathrm{HC} * \mathrm{RD\_OECD})_{t-1} + \delta_5 \ln(\mathrm{LRD} * \mathrm{RD\_USA})_{t-1} + \delta_6 \ln(\mathrm{HC} * \mathrm{RD\_China})_{t-1} + \delta_7 \ln(\mathrm{HC} * \mathrm{RD\_W})_{t-1} + \delta_8 \ln(\mathrm{HC} * \mathrm{FDI})_{t-1} + \varepsilon_t \quad (13)$$

Equation 13 represents the short and long term dynamics of ARDL model, whereas $\beta_0, \beta_1, \ldots, \beta_{12}$, are short run parameters, while parameters $\gamma_1, \gamma_2, \ldots, \gamma_{12}$ are represent long term association and $\varepsilon_t$ represent the error term. In addition, $\delta_1$, $\delta_2, \ldots, \delta_8$ represents interactive terms to capture the absorptive capacity of the labour force in case of Pakistan.

**Table 2. List of Variables and Abbreviation**

| Abbreviation | Operation Definition of Variables |
|---|---|
| **$LTFP_t$** | Total Factor Productivity Growth |
| **$LEMP_t$** | Employment Rate |
| **$LHC_t$** | Human Capital Index |
| **$LECI_t$** | Economic Complexity Index (As proxy of R&D Spillovers) |
| **$LFDI_t$** | Foreign Direct Index Inflow |
| **$LTOP_t$** | Trade Openness |
| **$LTech\_Imp_t$** | Technological Imports as Percentage of Total Import |
| **$LUT_t$** | University Teachers as a proxy of researcher across Pakistan |
| **$LTech\_Exp_t$** | Technological Exports as a percentage of merchandize exports |
| **$LUni_t$** | No of Universities as proxy of research institutions expenditures |
| **$LRD\_OECD_t$** | Spending on R&D done by OECD Countries |
| **$LRD\_USA_t$** | Expenditures on R&D done by USA |

| Abbreviation | Operation Definition of Variables |
|---|---|
| **$LRD\_China_t$** | R&D Expenditures done by China |
| **$LRD\_W_t$** | R&D Expenditures done across the Globe |

*Source:* authors' own.

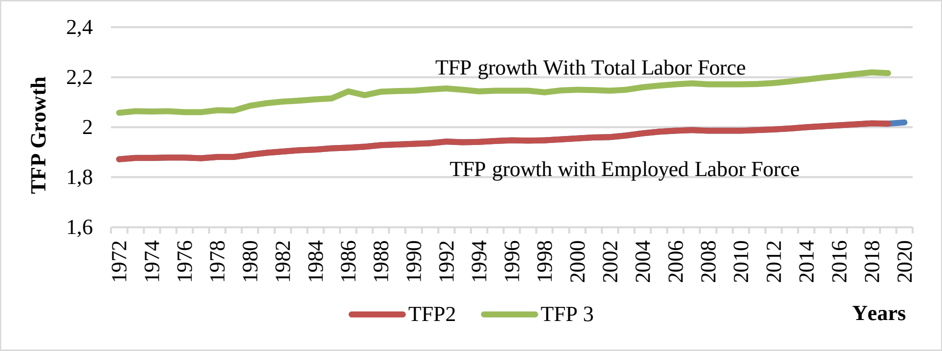
# 3 Results and Discussion

## *3.1 R&D spillovers and TFP growth*

R&D diffusion performs an essential role in manufacturing, agricultural and services sectors through the channels of innovation adoption, technological transformation and knowledge capital. An economic R&D consists of factors including innovation expenditures either domestic or foreign, trade openness, FDI, technology imports and export. The noneconomic factors consist of R&D structures, incentive system, innovation environment, and factors related to absorptive ability. Analysis techniques are adopted according to the nature and limitation of the data, the requirement of the model, and the assumption of the study. Different data cleaning and screening tools are applied to avoid unbiased, spurious, and inconsistent analysis. For empirical analysis this research adopted the following techniques such as unit root test, ARDL model, Cobb-Douglas (CD) and Translog production function. For results, the accuracy and cleaning of several residual diagnostic and remedial tests are also applied. The CD production function is appropriate for measuring TFP growth using conventional time series data of aggregate inputs such as labour and capital.

Figure 3 shows the computed graph of the growth of TFP in Pakistan. The increase in TFP exhibits a favourable rising trend. In 2020, TFP growth was remained at 2.01%, which is less than the 2.90 percent global TFP growth (World Bank, 2021). To ensure the efficiency of the full-employment level, the calculated value of TFP with the total labour force is 2.21, while TFP growth with the employed labour force is 2.01. The gap in TFP growth shows that Pakistan has the potential to achieve higher productivity through reduction of unemployment. Higher TFP growth can achieve through spending in R&D and knowledge capital to improve innovation and human capital efficiency.

**Figure 3. TFP growth of Pakistan**




*Source:* author’s own estimation.

## *3.2 Unit Root Test*

The trending behaviour of the time series data analysis may cause a problem of spurious analysis. This problem can be resolved by examining the stationarity behaviour and adopting the suitable analysis techniques in light of the unit root results. The augmented Dickey-Fuller (ADF) technique is applied to identify the stationary level of the given variables, the results shown in Table 3. According to ADF outcomes, the explained variable is integrated at the first difference, while the independent variables have mixed stationarity behaviour, some variables are integrated at level and few variables are integrated at the first difference. This demonstrated that the adoption of R&D from earlier periods and skilled base knowledge capital is crucial for Pakistan's TFP growth. For optimal lag selection, the Akaike Information Criterion (AIC) provides robust results compared to the Schwarz-Bayes Criterion (SBC) and Hannan-Quinn Criterion (HQC), as the results emphasised that lag 2 is optimal lag and suitable for given sample size.

**Table 3. Results of the ADF test for R&D spillovers and TFP growth**

| Variables | Level | | First Difference | |
|---|---|---|---|---|
| | T-stat | P-Value | T-stat | P-Value |
| $TFP_t$ | | | -5.12* | 0.0001 |
| $EMP_t$ | | | -4.31* | 0.0012 |
| $HC_t$ | | | -6.68* | 0.0000 |
| $ECI_t$ | | | -5.47* | 0.0002 |
| $FDI_t$ | -3.37* | 0.0675 | | |
| $TOP_t$ | -5.08* | 0.0007 | | |
| $Tech\_Imp_t$ | | | -6.92* | 0.0000 |
| $UT_t$ | | | -5.91* | 0.0000 |
| $Tech\_Exp_t$ | | | -7.10* | 0.0000 |
| $Uni_t$ | | | -6.74* | 0.0000 |
| $LRD\_OECD_t$ | -6.31* | 0.0000 | | |
| $LRD\_USA_t$ | -7.94* | 0.0000 | | |
| $LRD\_China_t$ | | | -4.63* | 0.0005 |
| $LRD\_W_t$ | | | -6.86* | 0.0000 |

*Note:* *Indicates the level of the stationarity of respective variable.
Source: author's own calculation.

## *3.3 Long-Term Coefficient of R&D Spillover on TFP Growth*

The long-term analysis uses time-series data to figure out what is going on with trends and what might be wrong with an analysis. To avoid spurious analysis, the problem of multicollinearity is found during the data cleaning process. Due to interacting terms and tighter proxy of R&D spillovers, the problem of multicollinearity emerged. For this reason, many models' estimates include the addition of R&D adoption proxies. The ARDL method of cointegration is applicable for the final empirical results since the outcomes of the ADF test demonstrate that all the selected variables are integrated at the level or 1st difference (I(0) or I(1)). To prevent multicollinearity, seven models are estimated using the dynamic autoregressive distributive lag (ARDL) technique. The analysis results of all estimated models are given in Table 4.

The estimated results of all models show that the penetration of R&D creates positive externalities for the growth of Pakistan. The results highlight that international R&D has greater magnitude with positive spillover shock compared to local R&D to enhance TFP growth. The calculated values of the absorptive capacity of R&D absorptive ability indicate negative and significant, which emphasised that Pakistani labor force has less knowledge capital and poor absorption capacity. The empirical results of R&D expenditures around the globe have positive spillover shocks in Pakistan's TFP growth, while R&D expenditure from OECD countries creates negative externalities for TFP growth. In all seven specifications, Human Capital ($HC_t$) and Employment ($EMP_t$) are considered control variables. The estimated value of $HC_t$ in all estimated models shows mixed results, in three models, $HC_t$ has positive and significant results, while in four models, $HC_t$ has insignificant results.

In the first estimated model, the explained variable is TFP growth ($TFP_t$), while the predictor variables are employment ($EMP_t$), Human Capital ($HC_t$), Foreign Direct Investment ($FDI_t$), University Teachers (UTt) and interaction term of HC with FDI (HC*FDI). $EMP_t$ and $HC_t$ are control variables, while FDI is a proxy of foreign R&D and $UT_t$ is a proxy of domestic R&D. The calculated value of $EMP_t$ has a significant impact on $TFP_t$ with positive elasticity, the calculated value of $EMP_t$ shows one percent increase in employment has 17 percent contribution in TFP growth of Pakistan. Further, Moreno-Galbis (2012) concluded that TFP growth accelerates the jobs markets, increase the trained, skilled, and intensive to update job specific technology.

The efficient and knowledgeable worker force has productive impact on TFP growth. The value of the coefficient value of $HC_t$ demonstrated a positive and significant influence on the growth of Pakistan, this is due to the youth, energetic and abundant labor in the country. The coefficient of $HC_t$ shows 34 percent share in the growth of TFP in Pakistan. The study finding aligned with the findings of Moreno-Galbis (2012) who argued that human capital magnifies impact on growth through heterogeneous skilled labour, trained workers and complementary association between skills and technological innovation.

In the first model, foreign R&D spillovers is captured through $FDI_t$, the analysis results of external R&D adoption produce a significant affirmative effect on TFP growth in Pakistan. The coefficient elasticity of FDIt is 2.3 percent. Additionally, the advantages of FDI spillovers can be attained through effective human capital, skilled and efficient labour, and early adoption of foreign R&D innovation, for this, domestic factors, institutional development, and extension policies are crucial tools. Technology transfer from outside sources has made a significant contribution to TFP growth. Adopting innovation in R&D innovation is the first step toward increasing productivity, but for most developing nations, access to affordable new technology is a key problem (Abdullahi et al., 2015). The results are aligned with the findings of Ahmed et al. (2017), who investigated the positive association between FDI inflow and TFP growth. Khan et al. (2017) and Lapple et al. (2016) argued that R&D spending on foreign R&D and innovative technology has a positive impact on TFP growth.

The variable of university teachers ($UT_t$) is used to measure the domestic R&D spillovers, as university faculty is considered a fundamental source of knowledge spillovers across the country. The calculated coefficient value of $UT_t$ is insignificantly negative. The insignificant value of $UT_t$ directed that domestic R&D spillover has not perform any fundamental contribution in TFP growth. The reason for the insignificant impact of $UT_t$ is that the university faculty are not up to date and do not generate the knowledge and its spillovers shocks for the society to boost the TFP growth in the long term. In addition, Martin (1998) concluded that university research accelerates the TFP growth through development of new product, country support in favourable knowledge intensive product and innovative product competitive at market globally.

Through an interactive term of human capital ($HC_t$) with $FDI_t$, the researcher captured the absorptive capacity of the Pakistani workforce. The efficiency of R&D spillover is dependent on the absorbent ability of the host country, and knowledge-based labour can utilise foreign R&D efficiently (Coe et al., 2009). The interaction term's negative, significant result suggests that the labour force's absorptive capacity is lower. The Pakistani labour force is incapable of effectively using foreign technology. The results of the interaction term indicated that either educated labour is not readily available or that knowledge capital is insufficiently efficient to absorb foreign innovation. The findings are in line with those of Nadeem et al. (2013), Chandio et al. (2016) and Khan et al. (2017), who discovered that the lack of absorption ability makes human capital, experience, and training have little bearing on productivity. To achieve better TFP growth through spillover of technology, human capital investment is necessary to boost labour productivity.

In the second specification, the explained variable is the TFP growth ($TFP_t$), whereas the explanatory variables are employment ($EMP_t$), Human Capital (HC), trade openness ($TOP_t$), Technology Exports ($Tech\_exp_t$), and the interaction term of HC with $TOP_t$ (HC*TOP). The $EMP_t$ and $HC_t$ are control variables, while $TOP_t$ is a proxy of international R&D and $Tech\_exp_t$ is a proxy of domestic R&D. The calculated coefficient value of $EMP_t$ has a significant impact in $TFP_t$ with positive elasticity and has a similar impact as in the model first. However, the coefficient value of $HC_t$ shows a positive and insignificant impact on the growth of TFP in second specification.

**Table 4. Long-Run Results TFP Growth and R&D Spillovers Model**
**The dependent variable is TFP growth.**

| Variables | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
|---|---|---|---|---|---|---|---|
| **C** | 1.244*** (0.000) | 1.356*** (0.000) | 0.676*** (0.000) | 0.171* (0.059) | 0.237*** (0.001) | 2.420*** (0.007) | 1.255*** (0.000) |
| **$EMP_t$** | 0.173*** (0.000) | 0.140*** (0.000) | 0.341 (0.125) | 0.133*** (0.000) | 0.140*** (0.000) | -0.486*** (0.014) | 0.130*** (0.000) |
| **$HC_t$** | 0.343*** (0.001) | 0.151 (0.235) | 1.339** (0.018) | 0.024*** (0.005) | 0.001 (0.820) | 0.185*** (0.013) | 0.541 (0.245) |
| **$ECI_t$** | | | -0.012* (0.089) | -0.009** (0.025) | -0.017*** (0.000) | -0.078*** (0.003) | -0.003 (0.441) |
| **$FDI_t$** | 0.023*** (0.000) | | | | | | |
| **$TOP_t$** | | 0.003** (0.014) | | -0.002 (0.713) | 0.009*** (0.008) | 0.139*** (0.009) | -0.017 (0.209) |
| **$Tech\_Imp_t$** | | | 0.447*** (0.000) | | | | |
| **$UT_t$** | -0.004 (0.199) | | | | | | |
| **$Tech\_Exp_t$** | | 0.003*** (0.001) | | | | | |
| **$Uni_t$** | | | 0.183*** (0.000) | | | | |
| **$LRD\_OECD_t$** | | | | -0.233*** (0.000) | | | |
| **$LRD\_USA_t$** | | | | | 0.055*** (0.000) | | |
| **$LRD\_China_t$** | | | | | | 0.235*** (0.003) | |
| **$LRD\_W_t$** | | | | | | | 0.529*** (0.000) |
| **$HC*FDI_t$** | -0.015*** (0.000) | | | | | | |
| **$HC*TOP_t$** | | -0.007*** (0.008) | | | | | |
| **$HC*Tech\_Imp_t$** | | | -0.965*** (0.005) | | | | |
| **$HC*LRD\_OECD_t$** | | | | -0.229*** (0.000) | | | |
| **$HC*Lrd\_USA_t$** | | | | | -0.261*** (0.000) | | |
| **$HC*LRD\_China_t$** | | | | | | 0.021 (0.134) | |
| **$HC*LRD\_W_t$** | | | | | | | -0.962*** (0.000) |

Note: ***, **, * Indicates the level of significance of all respective variables at 1, 5 and 10%.
*Source:* author's calculation.

The foreign R&D spillovers is captured through $TOP_t$, the analysis results shows that TFP growth is positively affected by external R&D adoption in Pakistan. The coefficient elasticity of $TOP_t$ is 0.3 percent. Furthermore, $TOP_t$ has less foreign R&D spillover shocks as compared to FDI in the case of Pakistan. The $TOP_t$ spillovers can boost through /+more open economy, especially trade liberalisation with the technological advanced countries and improvements of internal knowledge diffusion. The $TOP_t$ benefits can be achieved through efficient human capital, skilled and efficient labour, and early adoption of foreign innovative technology, for this, domestic factors, institutions development and extension policies are important instruments to enhance long-term TFP growth. The adoption of R&D innovation is the initial step to enhance productivity; however, the affordability of new technology is a key issue for most of the developing economies (Abdullahi et al., 2015). The outcomes align with the findings of Lapple et al. (2016) and Khan et al. (2017) who argued that R&D spending on foreign technology and more open economies can achieve greater benefits from innovation spillovers.

The coefficient value of $Tech\_exp_t$ shows a positive and significant contribution to TFP growth in Pakistan. $Tech\_exp_t$ has a 0.3% contribution in TFP growth in Pakistan. The small coefficient value highlights that $Tech\_exp_t$ has a small contribution in innovation exports. Export to technological products has a small share to GDP growth in Pakistan, which is a central reason of inadequate contribution of technological exports in TFP growth. The results are aligned with the findings of Bolosha et al. 2022 concluded that technology exports and innovation management have a productive impact on TFP growth.

The interaction term $(HC*TOP)_t$ yields a substantial negative result, indicating that the absorptive capacity is lower. The labour force in Pakistan lacks the skills necessary to use foreign technologies. According to interactive-term outcomes, either there is either a lack of trained workers or the knowledge capital is inefficient enough to absorb foreign innovation. The results are aligned with the outcomes of Nadeem et al. (2013), Chandio et al. (2016), and Khan et al. (2017) who found that human capital, experience, and training have an insignificant impact on productivity due to poor absorption capacity.

In third estimated model, the explained variable is TFP growth ($TFP_t$), whereas the predictor is Employment ($EMP_t$), Human Capital (HC), Economic Complexity Index ($ECI_t$), Technology Imports ($Tech\_imp_t$), No of Universities (Unit), and interaction term of HC with $Tech\_imp_t$ (HC*Tech_Imp). The $EMP_t$ and $HC_t$ are control variables, while $Tech\_imp_t$ is a proxy of foreign R&D and $Uni_t$ is a proxy of local R&D. The $ECI_t$ is used to measure the current production capability and efficiency of the country. The estimated value of $EMP_t$ has an insignificant impact in $TFP_t$ with positive elasticity. The coefficient value of $HC_t$ has a similar result with miner change in coefficient magnitude as given in the first specification.

The foreign R&D spillovers is captured through Tech_impt, and the analysis results of external R&D adoption shows significantly positive effect on TFP growth in Pakistan. The coefficient of elasticity of $Tech\_imp_t$ is 44%. Additionally, the advantages of $Tech\_imp_t$ spillovers can be attained through effective human capital, skilled and efficient labour, and early adoption of foreign R&D innovations; for this, domestic factors, institutional development, and extension policies are crucial tools. Technology imports from abroad have a noteworthy impact on TFP growth.

Adopting R&D based new R&D-based technology is the first step toward increasing productivity, but for most developing nations, access to affordable new technology is a major problem (Abdullahi et al., 2015). The results are aligned with the findings of Ahmed et al. (2017), who investigated the positive association between FDI inflow and TFP growth. Lapple et al. (2016) and Khan et al. (2017) argued that R&D spending on foreign R&D and innovative technology has an optimistic impact on TFP growth.

The calculated value of $Uni_t$ shows a positive and significant contribution to enhance the TFP growth. The unit has 18 percent contribution in TFP growth. The coefficient value of $Uni_t$ highlights the increasing number of universities playing a productive role in TFP growth and innovation spillovers across the county. Pakistan is in the early stages of development and a growing number of universities perform productive role in increasing the literacy rate and human capital development. The estimated results indicate that Pakistan has to focus on university development by ensuring quality education. In addition, Martin (1998) concluded that university research accelerates the TFP growth through development of new product, country support in favourable knowledge intensive product and innovative product competitive at market globally.

The estimated results highlighted that $ECI_t$ has a significantly negative contribution to TFP growth. The estimated coefficient of $ECI_t$ has a negative and significant contribution in TFP having coefficient value of -0.012. This specifies that the knowledge accumulated by the Pakistani population is not translated into the production process. Furthermore, innovative ideas and unique research activities are not appreciated in the inclusive research and production process. The $ECI_t$ results indicate that knowledge generation system is very complex and not translated into innovative activities. The industrial production structure is not developed, producing the innovative products to compete at international market. The research results are aligned with Pazham and Salimifar (2016), who found the negative association between GDP growth and $ECI_t$ of chosen panel countries. The results of the interactive term are consistent with the findings of the model first, which shows that the technology imported from foreign sources is not absorbed efficiently.

In fourth, fifth, sixth, and seventh models, the independent variables are Employment ($EMP_t$), Human Capital (HC), Trade Openness ($TOP_t$), $ECI_t$, R&D expenditures did by USA ($RD\_USA_t$), R&D spending did by OECD economies ($RD\_OECD_t$), R&D spending did by China ($RD\_China_t$), and world R&D expenditures ($RD\_W_t$) and their interactive terms with Human Capital ($HC_t$) of Pakistan. $TOP_t$ is a proxy of foreign R&D and $ECI_t$ is a proxy of local R&D, while the other countries' expenditures on R&D is utilized to capture the shocks from the spillover of innovation towards Pakistan. The estimated results of the control variables and the proxies of domestic and foreign RDs are consistent with previously estimated models. The results of different interactive terms with other countries R&D spending shows an adverse and notable effect on TFP growth of Pakistan. This shows that the knowledge generated by the developed countries is not absorbed in Pakistan. The Pakistani workforce does not have the efficiency and knowledge capital for the effective use of foreign innovation.

The results of proxies of foreign R&D shows positive spillover shocks and helpful in TFP growth of Pakistan. The estimated coefficient value of $RD\_USA_t$, RD_Chinat, and $RD\_W_t$ shows a significantly positive contribution to enhance the TFP growth of Pakistan. The R&D expenditures done by the USA, China and World are creating the positive externalities for TFP growth in Pakistan, which is helpful in bringing the innovation and new production technique through positive spillover shocks. However, the R&D expenditures made by OECD countries ($RD\_OECD_t$) show a significantly negative contribution to reduce the innovation process and the growth of Pakistan. This means that innovation expenditures of the OECD countries are creating the negative externalities for Pakistani TFP growth.

## *3.4 Cointegration and Diagnostic Estimates*

The CUSUM and CUSUMQ tests are graphical analysis of the cointegration equation (called the ECM model) which is estimated in the ARDL model. The calculated values of CUSUM analysis and CUSUMQ tests lie within 5 percent bounds which is confirmation of the existence of a long-run association with selected variables and shows the stability in estimated coefficients (Alimi et al., 2014; Ali et al., 2019). To ascertain whether a relationship of cointegration exists, the bound test of ARDL is used (Pesaran et al., 2001). The calculated value of the ARDL bound test shows that F-stat values are greater than the upper bound in all estimated models, which indicated that the hypothesis of no long-run association is rejected significantly (Table 5). The estimates of ARDL model show that R&D spillover indicators have extended effect on TFP growth. The empirical results agree fairly well with the findings of (Liu et al., 2016).

**Table 5. ARDL bound test and diagnostic estimates of TFP growth models**

| **Bound Test** | **7.57** | **5.84** | **10.760** | **5.668** | **7.809** | **3.527** | **6.256** |
|---|---|---|---|---|---|---|---|
| **Heterosckedasticity** | 0.676 (0.816) | 0.595 (0.854) | 0.964 (0.536) | 0.366 (0.984) | 0.301 (0.993) | 0.792 (0.711) | 0.453 (0.562) |
| **Serial Correlation** | 2.785 (0.109) | 2.429 (0.107) | 1.322 (0.290) | 0.687 (0.414) | 1.045 (0.366) | 2.242 (0.121) | 1.245 (0.346) |

*Source:* author's own calculation.

## *3.5 Short Run Analysis and ECM Results*

The estimates of the short-term coefficients are given in Table 6. Since the estimated models are time series multivariate, so, the error correction model (ECM) is used to determine how stochastic trends will behave and how quickly the dependent variable will converge to equilibrium. The error correction mechanism ECM (-1) coefficient has a significantly negative sign at the 1 percent level in all estimated models, which shows that variables in estimated models are cointegrated in the long run. The coefficient of ECM implies that deviation from steady-state position in R&D spillovers in estimated models is corrected with fast speed of adjustment (Shittu, 2012). Disequilibrium can be corrected through R&D spillovers, that shocks can be modified with faster speed, and R&D spillovers perform an important role in TFP growth to bring its steady state position (Shita et al., 2019; Ali et al., 2020).

**Table 6. Short-run and ECM estimates of TFP growth models**

| Variables | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
|---|---|---|---|---|---|---|---|
| **D(LEMP)** | -0.0126 (0.4861) | -0.0129 (0.4193) | -0.1348*** (0.0000) | -0.0740*** (0.0074) | 0.0463 (0.1292) | -0.0233 (0.5633) | -0.1548*** (0.0054) |
| **D(LEMP(-1))** | -0.0719** (0.0259) | -0.0418 (0.2300) | -0.0053*** (0.0092) | -0.0976*** (0.0008) | | 0.0569 (0.2666) | 0.1053*** (0.0000) |
| **D(LHC)** | 0.1375*** (0.0045 | 0.0277 (0.5982) | 0.0520 (0.3719) | 0.0152** (0.0182) | 0.0296** (0.0166) | 0.0292*** (0.0000) | 0.0230 (0.1900) |
| **D(LHC(-3))** | | 0.2081** (0.0173) | | | 0.0281** (0.0168) | 0.0177* (0.0943) | |
| **ECI** | | | -0.0029 (0.1248) | -0.0174*** (0.0006) | -0.0050 (0.1630) | -0.0007 (0.7946) | -0.0015** (0.0160) |
| **D(FDI)** | 0.0092*** (0.0000) | | | | | | |
| **D(TOP)** | | | 0.0011** (0.0104) | -0.0015 (0.7167) | 0.0083** (0.0232) | -0.0085** (0.0471) | 0.1892*** (0.0089) |
| **D(LTECH_T)** | | | 0.0107** (0.0234) | | | | |
| **D(LUT)** | 0.0025** (0.0286) | | | | | | |
| **D(LUT(-1))** | -0.0019* (0.0927) | | | | | | |
| **D(TECH_EX)** | | 0.0004 (0.2114) | | | | | |
| **D(TECH_EX(-1))** | | -0.0005 (0.2552) | | | | | |
| **D(LUNI)** | | | 0.0077* (0.0915) | | | | |
| **D(LUNI(-1))** | | | -0.0081** (0.0244) | | | | |
| **D(INT)** | -0.0049*** (0.0001) | -0.0026*** (0.0063) | -0.0020 (0.8942) | -0.0885 (0.1246) | -0.0929*** (0.0000) | -0.0129** (0.0111) | -0.1214*** (0.0016) |
| **D(INT(-1))** | -0.0011*** (0.0087) | | | 0.0513 (0.3369) | 0.0289*** (0.0007) | | |
| **D(LRD_OECD)** | | | | 0.0134 (0.6909) | | | |
| **D(LRD_USA)** | | | | | 0.0480*** (0.0000) | | |
| **D(LRD_China)** | | | | | | -0.0031 (0.7521) | |
| **D(LRD_W)** | | | | | | | 0.1295*** (0.0000) |
| **ECM(-1)** | -0.4005*** (0.0000) | -0.3565*** (0.0000) | -0.2437*** (0.0000) | -0.6226*** (0.0000) | -0.8625*** (0.0000) | -0.3937*** (0.0019) | -0.5815*** (0.0000) |

*Note:* ***, **, * Indicates the level of significance of all respective variables at 1, 5 and 10%.
*Source:* author's calculation.

## 4 Conclusions and Policy Suggestions

This research was designed to investigate the proficiency of R&D spillovers and the capacity to absorb foreign knowledge is essential for the growth of TFP in Pakistan. It also investigates the efficiency of the labour force for progenitive utilization of R&D innovation. The quantitative analysis is carried out through the yearly time series information for the time frame of 1972 to 2022. The Translog and Cobb Douglas production functions were employed to measure the TFP growth, and Autoregressive Distributive Lagged (ARDL) model was applied for empirical results. The estimated results of all models show that the penetration of R&D creates positive externalities for the growth of Pakistan. The results highlighted that global R&D spending has optimistic spillover shocks compared to internal R&D shocks to enhance TFP growth. The calculated values of R&D absorptive ability of R&D indicated negative and significant, highlighting that Pakistani labor force has less knowledge capital with poor absorption capacity. The empirical results of R&D expenditures around the globe have positive spillover shocks in Pakistan's TFP growth, while R&D expenditure from OECD countries creates negative externalities for TFP growth. On the basis of the quantitative analysis, it is concluded that global R&D is more appropriate for economic growth compared to domestic R&D, and the Pakistani labor force has less absorptive ability.

The innovation index highlights that Pakistan lacks good research institutions, knowledge capital, technological innovation and infrastructure, and an environment for research, which is extremely important for the socio-and-economic development of the economy. The statistical and graphical representation of internal and foreign R&D drivers highlight that Pakistan has the potential to acquire benefits from both sources, such as foreign and domestic spillovers shocks of R&D. In terms of global R&D spillovers, Pakistan has the potential to attract foreign innovation through FDI, trade openness, and technology imports, but the domestic knowledge capital has a significant problem in absorbing external innovation. Now, it is time to realise and move on the importance of R&D expenditures for both the private and public sectors. A combined strategy is required to focus on inclusive innovation and spillovers of foreign knowledge. Internal innovation can improve through an increase in domestic R&D expenditure, improve research culture, incentive system, collaboration, and networking. Based on quantitative analysis, this study has the following suggested workable policies:

- The government should focus on sustainable policies related to internal R&D, R&D spillovers with sufficient and sustainable R&D expenditures.
- The Pakistani government needs to develop an institutional structure and ecosystem for R&D spillovers.
- A combined strategy is required to focus on domestic and foreign R&D innovation spillovers both in the public and private sectors.
- Domestic knowledge spillovers can be enhanced through an increase in domestic R&D expenditure, research culture, incentive system, collaboration, and networking within and across sectors.
- Research alliances are required among research institutions and public and private corporations, which is desperately needed to design the incentive and protection mechanism for private sector innovation to encourage future R&D spillovers.
- Linkages among research institutions, industries, and extension agents are required to boost the adoptability and capacity to absorb (knowledge capital).
- The government should focus on the R&D spending, human capital development, and achieving a full employment rate to boost the TFP growth.

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