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Asymmetric Association among Technological Spillover, Absorptive Capacity and Economic Development: A NARDL Approach

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Abstract: *The spillover of external research and development (R&D) capital stock and the level of domestic human capital, as a source of absorptive capacity, plays a vital role in stimulating economic growth and development. The objective of this study is to examine the asymmetric associations among human capital, R&D stock spillover, capital import intensity, and output growth in Pakistan over the period 1982 to 2020. For this purpose, we develop and estimate a nonlinear autoregressive distributed lag (NARDL) model. The results of the bounds test confirm the presence of a long-run relationship, while the error correction model confirms the convergence from short-run to long-run equilibrium among the variables. The impact of machinery and technological good imports is positive on per capita GDP in the long run. In contrast, the impact of external R&D capital stock is symmetric in the short but becomes negative in the long run. The relationship between human capital and per capita GDP appears to be asymmetric because of low spending in the education sector. Based on these findings, we suggest that Pakistan should enhance its share of imports of high-tech products and improve its absorptive capacity for the effective use of external R&D resources.*

Keywords: Asymmetric association, technology spillover, economic development.

JEL Classification: B23, O01, O10.

Asymmetric Association among Technological Spillover, Absorptive Capacity and Economic Development: A NARDL Approach

1. Introduction

Developments in science and technology have changed the sources of growth, particularly in the twenty-first century. Knowledge-based capital, which includes digital information, information and communication technology (ICT), innovation, international mobility of people and external technology, is the key to spurring new sources of output growth. Trade of capital goods, machinery and high-tech products and foreign direct investment (FDI) are the two most significant channels of external technological transformation. Both trade and FDI, as carriers of foreign technology and knowledge, have positive effects on the economic growth of the host country (Chengying et al., 2023). However, this positive role of external sources of technology and knowledge depends on the country's absorptive capacity.

Research and development (R&D) capital stock, both domestic and foreign, produces a sustainable level of production capabilities (Zhu et al., 2023). Empirical analysis shows that domestic R&D stock and expenditures by advanced economies on R&D affect innovation capacity, technological advancement and breakthroughs in the host countries and their trading partners (Grossman & Helpman, 1991). Crispolti and Marconi (2003) find that developing countries can benefit from active and passive spillovers through FDI and the import of capital goods and technology.

The import of capital-embodied goods enhances economic growth by incorporating a variety of foreign technological inputs into production processes, leading to massive spillovers. In comparison, active technological spillovers emerge if learning from foreign innovations and technology is purposive. Afzal and Mushtaq (2022) find that R&D yields a significant positive impact on the innovative capacity of growing economies. In this scenario, local firms not only adopt foreign technology spillovers but also build their technological capability to upgrade local production and innovation capacity.

Knowledge-based economic development tends to be concentrated in advanced industrial economies, while developing countries are generally not as involved in domestic R&D (Caetano & Marques, 2023). Developing countries emerge as technological followers and simply adopt the innovations of their developed counterparts. Developing countries are often trapped in a vicious cycle of insufficient R&D, which hampers economic growth (Fang et al., 2022). In response, this low economic growth does not enable developing countries to advance their knowledge production. This is why several less-developed countries (LDCs) that had tried to improve their economic growth were not successful.

This struggle for improvement in economic conditions is referred to as the ‘economic tragedy of the twentieth century’ in empirical research (Artadi & Sala-i-Martin, 2003). Foreign technological spillovers transferred through imports and FDI would have a substantial positive effect on the productivity of developing countries if they had adequate domestic R&D capital stock (Keller, 2004). A significant knowledge and technology base is necessary for sound economic growth in today's knowledge-based global economy. Developing countries can take advantage of developed countries' knowledge and R&D capital stock if they have adequate domestic R&D capital stock (Keller, 2010).

Pakistan could also utilize technological and R&D spillovers by importing capital and machinery goods from its developed trading partners. Because it has an insignificant level of R&D capital domestically (Ali & Akhtar, 2023), it could capture technology spillovers by formulating a trade policy biased toward developed countries that are technologically advanced and have a large domestic R&D capital stock. However, Pakistan's foreign technological absorption capacity will depend on its domestic human capital stock. If Pakistan does not possess a threshold level of human capital stock, it cannot spur the benefit of any technological transformation channel. The objective of this study is to examine the asymmetric associations among human capital, R&D stock spillover, import intensity of capital, and output growth of Pakistan from 1982 to 2020. For our empirical analysis, we apply the NARDL method (Shin et al., 2014). This model examines the nonlinearity and nonstationary of impulses simultaneously and can capture the short-run and long-run associations among variables.

Our paper contributes to the literature in two ways. First, it investigates the asymmetric associations among human capital, R&D spillover, capital import intensity, and output growth of Pakistan. Second, it estimates the impact of human capital as an absorption measure for capturing technological spillovers. External R&D is measured using the perpetual inventory method. In the case of Pakistan, this study evaluates the impact of international knowledge and technological spillovers on output growth by considering both channels of international technological spillover transfer. To the best of our knowledge, no research has been conducted on the asymmetric relationship between foreign technological spillovers and economic growth in Pakistan.

The rest of the study is organized as follows. The next section presents a review of the literature and hypothesis development. Section 3 describes the methodology, including model specification, data sources, construction of variables and estimation approach. Section 4 presents the discussion, and the last section presents the conclusion and policy suggestions.

2. Literature Review and Hypothesis Development

Knowledge is treated as a vital endogenous factor of economic development, following the endogenous growth theory presented by Romer (1990), Lucas (1988), and Grossman and Helpman (1991). Economic liberalization denotes trade liberalization and financial liberalization. The former refers to lessening trade restrictions, while the latter describes capital mobility through foreign direct and portfolio investment or labor force mobility. The effect of economic liberalization (good or bad) on LDC economies led to a key policy debate. Endogenous growth theory proposes that the sustainable growth of a country depends on technological innovation and progress as these factors have a multiplier effect on growth through the transmission of technological knowledge (Wang et al. 2019). Therefore, the domestic stock of technological knowledge is an aggregate of domestic and foreign technological knowledge (Stöllinger, 2013).

Kim and Lee (2004) explain that the spillover of foreign technological knowledge is inhibited by transnational innovation. The industrial knowledge and advanced technological capital stocks of developed countries have increased their global specialization. Thus, developing countries formulate links with developed countries to capture technology spillovers. This investment motive is termed 'technology acquisition' or 'technology sourcing' (Neven & Siotis, 1996). Therefore, we hypothesize that importing machinery and other technological goods will positively influence output growth in the short and long run.

Hypothesis 1: Imports of machinery and technological goods will positively impact output growth in both the short and long run.

Significant work has been done on why developing countries fail to capture the foreign R&D spillovers of advanced countries (Pandey et al., 2022). R&D spillovers refer to the procedure of utilizing process-oriented and product-oriented innovations diffused by developed countries. Such innovations lead to new production and higher production quality at a lower average cost. Griliches (1998) explains this typology of R&D spillover as knowledge spillovers and rent spillovers.

Knowledge spillovers are further categorized into two types of spillovers: 'imitation-enhancing' and 'idea-creating spillovers'. Imitation-enhancing knowledge spillovers refer to capturing and imitating unprotected codified knowledge by other innovators. Idea-creating knowledge spillovers refer to the importance of past accumulated knowledge stock in the creation of new knowledge and ideas. Mostly, product orientation leads to R&D activities and knowledge spillovers lead to R&D spillovers. Moreover, product innovation is less likely to be protected than knowledge spillovers (Los & Verspagen, 2003). We argue that technology spills over via knowledge spillovers. In this context, we postulate that foreign R&D capital stock positively influences output growth:

Hypothesis 2: Foreign R&D capital stock will likely impact output growth positively.

According to the convergence hypothesis of neoclassical growth theory, local investment in human and institutional capital is critical for technological diffusion in developing countries (Rosenberg & Frischtak, 1985). The role of human capital is also explained by Todaro and Smith (2020), Matousek and Tzeremes (2021), Wang et al. (2022) and Asaleye and Strydom (2022). The political elites in developing countries block such sources of technological development and structural change by opposing policies that develop an adequate absorption capacity if these policies contravene their interests, motives and advantages (Acemoglu & Robinson, 2006).

Griliches (1992) states that the rate of return from investing in physical infrastructure is much lower than that from investing in R&D. R&D spillovers are significant for survival in the global economy and enable competition among developed and developing countries (Coe & Helpman, 1995). Developing countries can utilize the domestic R&D capital stock of developed countries by ensuring that their import-to-GDP ratio is biased toward capital and technological imports from technologically advanced trade partners and toward capital imports.

Domestic R&D capital stock is also preliminary, along with foreign R&D capital stock. However, we have dropped this variable from the model because Pakistan does not have enough domestic R&D capital stock. In this context, we hypothesize that the relationship between foreign R&D capital stock and output growth is dependent on the absorptive capacity of the host country.

Hypothesis 3: The impact of foreign R&D capital stock on output growth depends on the absorptive capacity of the host country.

The importance of the quality of institutions in Colombian trade with the rest of Latin America was determined by Abreo et al. (2021). Their results highlight the significant impact of the institutional quality gap between Colombia and its trading partners, particularly regarding government effectiveness. Sabir et al. (2019) investigate the importance of institutions for FDI, using data from a panel of developing low-income and high-income countries for 1996–2016. They find that institutional quality benefits FDI for all categories of countries.

The long-run positive association between institutional quality and FDI is also revealed by Yakubu (2020), who applied the autoregressive distributed lag technique to data for Ghana for 1985 to 2016. A barrier to FDI-led growth is that emerging countries have less developed institutional frameworks than wealthy countries. The core place in global FDI is attributable to technological progress, while knowledge has a strong moderating influence (Sultana & Turkina, 2020). Similarly, Vu and Ho (2020) establish that FDI plays a crucial role in low-income provinces because of four key factors: human capital, level of openness, infrastructure and absorptive capacity of local enterprises.

The importance of FDI for output growth is also explained by You and Xiao (2022), Yu et al. (2021), Ciobanu (2021), and Farooq et al. (2020). Afzal and Ahmad (2018) analyze the sources of productivity growth to examine the impact of technological advancement on output growth. They find that ICT, governance and gross domestic investment positively and significantly impact the productivity of growing Asian economies. As a result, external technology is hypothesized to improve output growth if the host country has appropriate absorptive capacity regarding human capital development.

Hypothesis 4: External technology is likely to promote output growth only if the host country has an adequate level of absorptive capacity in terms of human capital development.

Li and Tang (2019) review the association between international trade and technological progress and find that trade significantly increases total factor productivity and encourages businesses to engage in R&D activity. Massini et al. (2023) find that foreign trade businesses conducting R&D are relatively more productive. Similarly, external knowledge via foreign trade and FDI plays a vital role in stimulating regional industrial growth (Wang et al., 2020). Solomon and van Klyton (2020) find that digital technology plays an important role in the growth of output in Africa. As a result, we postulate that foreign trade is likely to be an important source of external technology transmission and helps to increase output growth.

Hypothesis 5: Foreign trade, as an important source of external technology transmission, positively impacts output growth.

Afzal et al. (2020) investigate the critical sources of national innovative capacity among technologically advanced countries from 1996 to 2015. For this purpose, they empirically examine the impact of ICT, human capital development, R&D expenditure, governance, financial development (FD) and exposure to external technology (EET) on innovation capabilities, using fixed effects estimation. They find that human capital, R&D expenditure, governance, FD and EET generate important positive roles in enhancing innovation. While several studies on Pakistan, such as Hye (2012), Jawaid (2014), Adeel-Farooq et al. (2017) and Yasmin et al. (2006), have explored the association between liberalization and economic growth, no study has assessed the asymmetric relationship between foreign technology-embodied capital imports and domestic technological breakthroughs of advanced trading partners on Pakistan's economic growth. Therefore, we form the following hypotheses.

Hypothesis 6: There is a long-run association among human capital, R&D stock spillover, capital import intensity, and output growth in Pakistan.

Hypothesis 7: The model will likely be stable and converge from short-run to long-run equilibrium.

3. Methodology

This section presents our empirical analysis, including the model specification, definitions and construction of variables, sources of data, and techniques of estimation.

3.1. Model Specification

The benefits of foreign R&D depend on absorptive capacity and learning and social capabilities such as social institutions, technological and educational competencies, the degree of infrastructure, and capital intensification in follower countries (Abramovitz, 1986; Baumol et al., 1989; Intisar et al. 2020). Coe et al. (1997) and Coe and Helpman (1995) find that international technological diffusion via machinery imports positively impacts the GDP of developing countries by stimulating productivity. Liu and Fan (2020) argue that international technological spillovers have a nonlinear association with economic growth, that is, various absorptive capacity factors maximize spillover effects when they are within two thresholds. Foreign R&D capital stock has an asymmetric association with economic growth as its positive and negative shocks have different impacts on growth.

Filippetti et al. (2016) explain that human capital has different effects on the absorption of technology spillovers domestically by influencing the turning point. The effect of spilled-over R&D stock, technology and knowledge transmission on economic growth depends on various absorptive capacity factors. After reaching a certain level of absorptive capacity, the positive influence of spillovers on the productivity and growth of the host country tends to emerge. A positive technology spillover effect may arise after a predetermined threshold as foreign and domestic enterprises' shares (Cantwell, 1989) and industrial growth attributes (Chen & Chen, 2006).

Developing countries with more open economies and a greater fraction of imports from developed countries rich in domestic R&D can capture more technology from abroad. However, the relative absorption of these spillovers depends on domestic attributes such as human capital, infrastructure and openness (Coe et al., 1997; Coe & Helpman, 1995; Jedwab et al., 2023; Nainggolan et al., 2022). Based on this discussion, the functional association can be expressed as follows:

$$\ln(Y)_t = \beta_0 + \beta_1 \ln(L)_t + \beta_2 \ln(K)_t + \beta_3 (MKG)_t + \beta_5 (FR\&D)_t + \beta_6 \ln(HR)_t + \mu_t \quad (1)$$

3.2. Definitions and Sources of Data

We analyze the asymmetric relationships among per capita GDP, imports of machinery and capital goods, level of foreign R&D capital and human resources from 1982 to 2020. The data for per capita GDP, imports of capital goods, FDI and human capital have been obtained from the World Bank. The data on the labor force has been taken from the Pakistan Economic Survey. External R&D capital stock is measured using the perpetual inventory method, and sourced from the science and technology indicators of the OECD. In this model, GDP per capita is a proxy for output growth, and is denoted by Y_t. K, L, MKG, FR&D and HR represent gross fixed capital formation, employed labor force, imports of machinery and capital goods, external R&D capital and human capital, respectively. Human capital is measured as total enrollment in all educational institutions in Pakistan.

3.3. Construction of Variables

We measure external R&D capital as the domestic R&D expenditures of import partners, with the output ratio of the host country as a weight. Foreign R&D capital stock is measured using the real gross R&D expenditure of Pakistan's developed and advanced bilateral trading partners. The perpetual inventory method is used to calculate the R&D stock (S), using data for domestic R&D expenditures:

$$S_t = (1-\alpha)S_{t-1} + R_{t-1} \tag{2}$$

where α indicates the standard 5 percent depreciation rate. Griliches' (1988) procedure has been used to calculate the benchmark R&D capital stock (S) as:

$$S_0 = {}^{R_0}\!\big/_{(g+\alpha)} \tag{3}$$

where g denotes the average annual growth of domestic expenditures on R&D over the available reported R&D data, R_0 is the initial R&D data for the first year and S_0 denotes the benchmark level of R&D capital for a technologically advanced country.

3.4. Estimation Techniques

The nonlinear autoregressive distributed lag framework (NARDL) developed by Shin et al. (2014) is used to estimate the model. NARDL is a popular technique for analyzing asymmetric and nonlinear relationships and is applied in different fields from energy economics and real estate economics to macroeconomic analysis. Several researchers have explored asymmetries in the impact of global trade spillovers on recipient countries in this manner. The NARDL method is flexible in terms of the order of integration of the impulses: variables may be integrated of order I(0)/I(1) or a combination of both can be used (Shin et al., 2014).

This model simultaneously examines the nonlinearity and nonstationarity of impulses and can also capture the short-term and long-term asymmetric effects among variables. The NARDL method is deemed superior to smooth transitions as it simultaneously produces valid results for short-run and long-run co-integration and asymmetries for small sample sets (Ahmad et al., 2016). This method solves the multicollinearity problem by using appropriate lags for the impulses (Shin et al., 2014). The asymmetric error correction model under NARDL is specified as follows:

$$\begin{aligned}\Delta Y_t = {} & \alpha + \rho Y_{t-1} + \delta_1^+(MKG)_{t-1}^+ + \delta_2^-(MKG)_{t-1}^- + \delta_3^+(FR\&D)_{t-1}^+ + \\ & \delta_4^-(FR\&D)_{t-1}^- + \delta_5^+(HR)_{t-1}^+ + \delta_6^-(HR)_{t-1}^- + \delta_7^+(K)_{t-1}^+ + \\ & \delta_8^-(K)^- + \delta_9^+(L)_{t-1}^+ + \delta_{10}^-(L)_{t-1}^- + \textstyle\sum_{i=1}^m \alpha_1 \Delta Y_{t-i} + \\ & \textstyle\sum_{i=0}^m \alpha_2 \Delta(MKG)_{t-i}^+ + \sum_{i=0}^m \alpha_3 \Delta(MKG)_{t-i}^- + \\ & \textstyle\sum_{i=0}^m \alpha_4 \Delta(FR\&D)_{t-i}^+ + \sum_{i=0}^m \alpha_5 \Delta(FR\&D)_{t-i}^- + \\ & \textstyle\sum_{i=0}^m \alpha_6 \Delta(HR)_{t-i}^+ + \sum_{i=0}^m \alpha_7 \Delta(HR)_{t-i}^- \sum_{i=0}^m \alpha_8 \Delta(K)_{t-i}^+ + \\ & \textstyle\sum_{i=0}^m \alpha_9 \Delta(K)_{t-i}^- \sum_{i=0}^m \alpha_{10} \Delta(L)_{t-i}^+ + \sum_{i=0}^m \alpha_{11} \Delta(L)_{t-i}^- + \mu_t \end{aligned} \quad (4)$$

In this equation, α_I refers to short-run coefficients and δ_i refers to long-run coefficients, with i = 1…11. The short-run analysis reveals the immediate effect of changes in the autonomous variables on the response variable. The long-run analysis demonstrates the time and speed of the adjustments of the exogenous variables toward the equilibrium level. We apply the Wald test for long-term asymmetry ($\delta = \delta^+ = \delta$) and short-run asymmetry ($\alpha = \alpha^+ = \alpha$) checks for all impulses. Y_t represents economic growth, MKG_t denotes the capital goods import intensity, $FR\&D_t$ denotes foreign R&D capital stock, HR_t denotes human resources, and K_t and L_t represent capital and the employed labor force, respectively. M represents the optimal lag length for Y_t and autonomous variables (MKG_t, $FR\&D_t$, HR_t, K_t, and L_t) as specified by the Akaike information criterion (AIC).

To assess the impact of increases and decreases in the autonomous variables, they are decomposed into negative and positive partial sums:

$$x_t^+ = \textstyle\sum_{i=1}^m \Delta x_i^+ + \sum_{i=1}^m \max(\Delta x_i, 0) \quad (5)$$

$$x_t^- = \textstyle\sum_{i=1}^m \Delta x_i^- + \sum_{i=1}^m \min(\Delta x_i, 0) \quad (6)$$

where x_t denotes MKG_t, $FR\&D_t$, HR_t, K_t, L_t. For an asymmetric long-term co-integration check, Shin et al. (2014) have developed a joint test for all lagged independent levels of variables—the bounds test. We use the F-statistic proposed by Pesaran et al. (2001) for short-run and long-run co-integration evaluation. The F-statistic tests the null hypothesis of $\delta = \delta^{+} = \delta = 0$. If the null hypothesis of no co-integration is rejected, then the F test suggests a long-run relationship among the variables. Before estimating the model, the augmented Dickey-Fuller (ADF), Phillips Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests are applied to examine the stationarity status of the impulses.

4. Results and Discussion

4.1. Descriptive Statistics

The descriptive analysis is given in Table 1. The results show that imports of capital goods are more volatile than FDI and external R&D capital stock. Gross fixed capital formation and education levels are about equally volatile, showing the low-capital deepening of Pakistan's economy. Labor is the least volatile, showing relative stability over the whole sample. Furthermore, the skewness and Jarque-Bera statistics show the asymmetric and non-normal distribution of the data series, which is why asymmetric methods and analysis have been applied.

Table 1: Descriptive Statistics

Variable	Mean	Median	Max.	Min.	SD	Skewness	Kurtosis	Jarque B.	Probability
Yt	6.50	6.30	7.30	5.81	0.51	0.28	1.54	3.96	0.14
K	13.41	13.43	15.68	11.00	1.50	-0.07	1.69	2.82	0.24
L	3.67	3.62	4.12	3.22	0.31	0.11	1.46	3.91	0.14
MKG	31.82	32.00	42.00	23.00	4.98	0.01	2.29	0.81	0.67
FR&D	8.08	8.24	8.61	5.79	0.58	-2.52	9282	105.58	0.00
EDU	13.31	13.30	14.73	11.66	1.05	-0.16	1.647	3.14	0.21
FDI	0.01	0.01	0.04	0.00	0.01	2.21	7.48	64.51	0.00

Note: K, L, MKG, FR&D, HR, and FDI represent gross fixed capital formation, employed labor force, imports of machinery and capital goods, foreign R&D capital, human capital, and foreign direct investment, respectively.

4.2. Econometric Results

To ensure the absence of any series integrated of order 2 or I(2), the stationarity properties of the variables are checked. A unit root analysis is needed to confirm the order of integration and analyze the co-integration among all the determinants using the NARDL technique. The augmented Dickey-Fuller (Dickey & Fuller, 1979), Phillips Perron (Phillips & Perron,

1988) and Kwiatkowski et al. (1992) stationarity tests are applied and their results are reported in Table 2. The empirical evidence shows that all variables are stationary at the first difference with the intercept and trend, except for gross fixed capital formation and FDI. Neither contains a unit root at level with the intercept and trend. The PP unit root test gives a similar empirical evidence for all variables. The KPSS test generates a different result.

Table 2: Results of Unit Root Tests (without structural break)

Variables	ADF		PP		KPSS	
	Level	1st Diff.	Level	1st Diff.	Level	1st Diff.
Y	2.371	5.579***	2.458	5.564***	0.151***	0.163***
L	1.576	6.338***	1.586	6.338***	0.1236***	0.6181***
K	5.455***	6.549***	5.454***	29.408***	.0740***	0.3037
MKG	3.013	3.444*	2.868	4.544***	0.068***	0.0518***
FR&D	2.950	5.812***	7.320***	5.813***	0.176***	0.173***
FDI	3.071**	4.116**	1.848	3.944***	0.1097***	0.040***
HR	2.109	6.401***	2.185	6.438***	0.109***	0.075***

Note: *, **, and *** indicate level of significance at 10%, 5% and 1%, respectively.
K, L, MKG, FR&D, HR, and FDI represent gross fixed capital formation, employed labor force, imports of machinery and capital goods, foreign R&D capital, human capital, and foreign direct investment, respectively.

The bounds test results for co-integration are reported in Table 3. At the first difference, all impulses are stationary. Accordingly, we apply the NARDL bounds testing method to check for asymmetric co-integration among the variables. Co-integration analysis is sensitive to the lag length selection for the model. We follow the SIC for this model and use one lag for all variables. The value of the F-statistic shows long-run co-integration as it is greater than the lower bound and upper bound values of the F-statistic at the 10, 5 and 1 percent significance levels. The results in Table 3 indicate that all the variables have a significant long-run relationship with Pakistan's GDP per capita.

Table 3: Bounds Test for Co-integration

Model specification	F-statistic	@ 10% level of significance		@ 5% level of significance		@ 5% level of significance		Conclusion
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	
Linear	5.005	2.12	3.23	2.45	3.61	3.15	4.43	Co-integration
Nonlinear	4.358	1.83	2.94	2.06	3.24	2.54	3.86	Co-integration

The short-run results of the NARDL model in Table 4 reveal that negative human capital shocks are significant in the short run and show that a decrease in human capital in any mode, such as human capital flight, has a nonlinear asymmetric association with economic growth. In comparison, its positive shocks have an insignificant impact on economic growth due to low-quality education, which is incompatible with functioning as absorptive capacity for foreign technological knowledge spillovers. This finding is supported by Mayer (2001), who shows that education and skills in terms of quality are incompatible with and inadequate for the use of technologically specialized imported machinery by the labor force in LDCs.

Likewise, the negative shock of machinery and capital goods imports has an asymmetric and significant impact on per capita GDP. However, the negative shock of foreign R&D capital stock has a significant symmetric relationship with per capita GDP. A decrease in foreign R&D capital stock negatively affects economic growth because of low absorptive capacity and lack of essential prerequisite investment and measurements, i.e., financial deepening, infrastructure quality and political stability. This symmetry of economic growth and foreign R&D capital stock is because the absorptive capacity is at less-than-threshold level. Without a minimum threshold level of human resources, domestic firms cannot use technology transformation via FDI and other channels (Taylor & Smith, 2007).

Table 4: NARDL Model Short-run Results

Dependent Variable: Per Capita GDP			
Variables	**Coefficients**	**Standard Error**	**t- Statistics**
ΔK_	0.087308	0.026119	3.342675***
ΔK+	0.401571	0.089138	4.505075***
ΔL_	-0.811383	0.942318	-0.861050
ΔL+	0.977828	0.425732	2.296816**
ΔHR_	0.523241	0.232407	2.251396**
ΔHR+	-0.052198	0.099877	-0.522623
ΔMKG_	0.008189	0.003370	2.430088**
ΔMKG+	0.006380	0.006285	1.015140
ΔFR&D_	-0.000084	0.000029	-2.848862*
ΔFR&D+	0.000006	0.000029	0.218622
ΔECMt-1	-0.877004	0.160788	-5.454410***

Note: *, **, *** indicate significance levels of 10%, 5% and 1%, respectively.
K, L, MKG, FR&D, and HR represent gross fixed capital formation, employed labor force, imports of machinery and capital goods, foreign R&D capital and human capital, respectively. ECM represents the error correction model.

The positive shocks of import intensity and foreign R&D capital stock show that the associations of these variables with economic growth are symmetric. Our results are consistent with the empirical literature, which shows that foreign spillovers obtained by imports of capital and technology-embodied imports and bilateral trade with advanced countries modify the domestic production function along with capital accumulation and explain Solow's residual growth (Œe et al., 2009). The error correction coefficient (ECMt−1) confirms that all the impulses of this model go together in the long run. The coefficient of the error correction term is −0.87 percent, which confirms that the model will adjust from short-run disturbance to long-term equilibrium at an 87 percent speed of adjustment per year.

The long-run results in Table 5 show that the positive shock of imports of capital goods—including machinery, capital and transportation equipment—has a positive impact on Pakistan's per capita GDP. Imports of capital goods have a symmetric association with economic growth. An increase in the import of capital has a significant positive relationship with economic growth, which is consistent with the findings of Coe et al. (1997) and Coe and Helpman (1995). Capital intensity is very important for the industrialization of developing countries as it increases the domestic value-addition process and international competition by altering the production function and upgrading labor force skills. Furthermore, it paves the way for FDI by increasing the confidence and incentives of foreign investors and transferring foreign technology to the LDC (Romer, 1990). Foreign R&D capital stock has an asymmetric association with economic growth as its positive shock has an inverse impact on economic growth in Pakistan.

Table 5: NARDL Model Long-run Results

Dependent Variable: Per capita GDP			
Variables	**Coefficients**	**Standard Error**	**t- Statistics**
K_	0.547415	0.143503	3.814657***
K+	0.411235	0.119544	3.440029***
L-	2.986925	1.114423	2.680244***
L+	1.462337	0.498686	2.932379***
HR_	0.596623	0.307948	1.937414*
HR+	-0.059519	0.117007	-0.508678
MKG_	0.009337	0.004001	2.333691**
MKG+	0.017981	0.006493	2.769066*
FR&D_	-0.000095	0.000031	-3.050206**
FR&D+	-0.000178	0.000048	-3.730430***

Note: *, **, *** indicate levels of significance at 10%, 5% and 1%, respectively.
K, L, MKG, FR&D, and HR represent gross fixed capital formation, employed labor force, imports of machinery and capital goods, foreign R&D capital and human capital, respectively.

Our results are aligned with the findings of Liu and Fan (2020). They find that international technological spillovers have a nonlinear association with economic growth, that is, various absorptive capacity factors maximize spillover effects when they are within two thresholds. This is a channel for the transfer of international technological spillovers. However, the effect of this spillover on the productivity of different countries may vary according to their national attributes and efficiencies. More specifically, technological spillovers generally crowd out the independent innovation capability of developing countries, but have a 'crowding-in effect' on developed countries.

The threshold level effect suggested by Borensztein et al. (1998) leads to a specific level of national absorptive capacity and capabilities that can be positively influenced by technology transmission. The positive effect of external technology can be obtained after a predetermined threshold level as foreign and domestic enterprises' shares (Cantwell, 1989). However, Pakistan does not have adequate threshold levels of different absorptive capacities, and so foreign R&D capital stock has significant negative links with economic growth. Developing countries with more open economies and where a greater fraction of imports comes from developed countries rich in R&D capital can capture more technological knowledge from abroad. Nevertheless, the relative absorption of these spillovers depends on domestic attributes such as human capital, infrastructure and openness (Coe & Helpman, 1995; Coe et al., 1997).

The results of the Wald test for asymmetric relationships are given in Table 6. The results show significant F values for both short-run and long-run asymmetry, which confirms the presence of an asymmetric relationship.

Table 6: Wald Test of Asymmetric Associations

Null Hypothesis	F-statistic	Probability
HYP2: for long-run asymmetry	5.9414	0.0004
HYP3: for short-run asymmetry	6.9414	0.005

The results of the Ramsey RESET test, LM test for autocorrelation, Harvey test for heteroskedasticity and Jarque–Bera normality test are given in Table 7. The results of all these diagnostic tests confirm that the model is specified correctly and has no autocorrelation or heteroskedasticity issues. The result of the Jarque–Bera normality test confirms that the model is normal. Similarly, the analysis of CUSUM and CUSUM squares given in Figures 1 and 2 reveals that the model is, overall, stable in the long run.

Table 7: Diagnostic Tests

Diagnostic tests	F-statistic	Probability
Ramsey RESET test for model specification	0.604563	0.4469
LM autocorrelation test	1.444765	0.2633
Harvey heteroskedasticity test	1.843985	0.0995
Jarque-Bera normality test	0.8341	0.6589

Figure 1: CUSUM

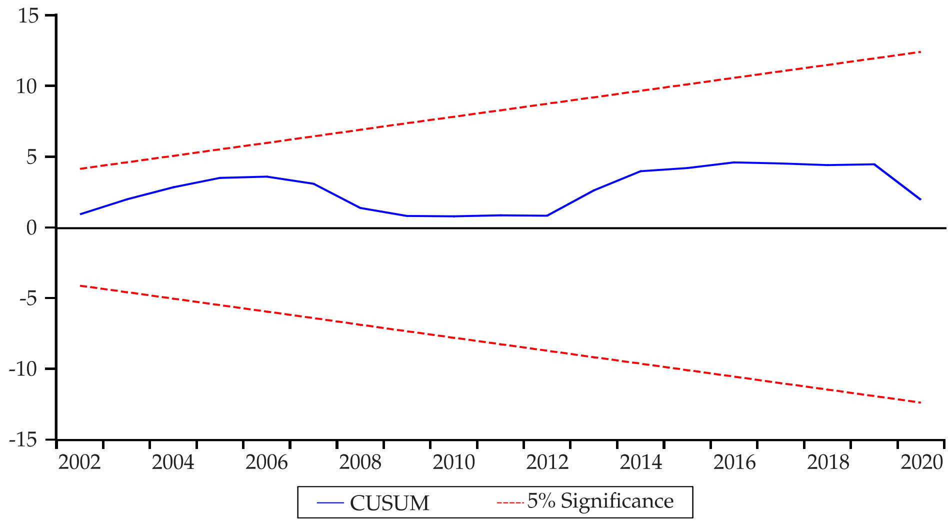
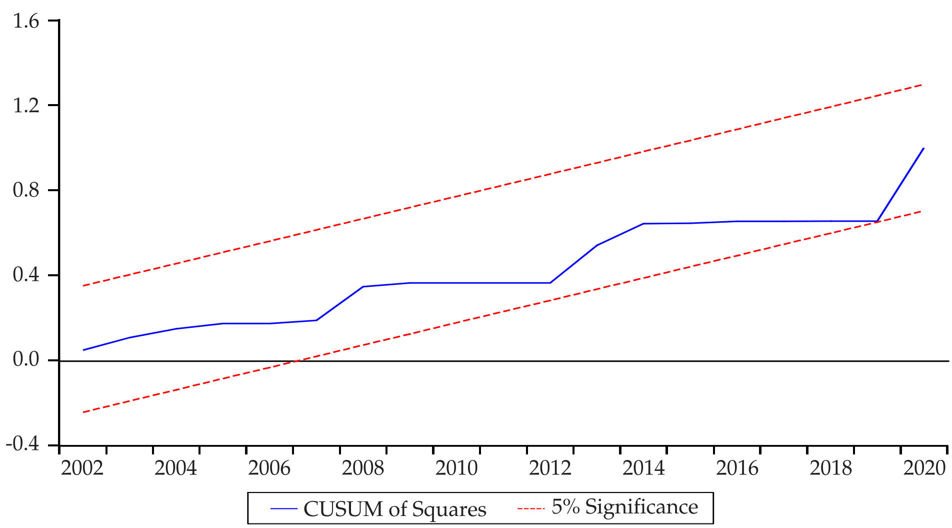


Figure 2: CUSUM Squares



5. Conclusion

This study investigates the asymmetric impact of capital imports and foreign R&D capital stock on Pakistan's economic growth, augmented by human capital as a measure of absorptive capacity, during the period 1982–2020. The ADF, PP and KPSS unit root tests have been used to check the stationarity status of the impulses. The descriptive statistics confirm the nonlinearity of the data. Our theoretical and empirical analyses explore the asymmetric relationships among the model variables. We apply a NARDL model to estimate long-run asymmetries in the variables. The ECM for checking short-run to long-run adjustment has a value of 87 percent and shows the speed at which Pakistan's economic growth returns to equilibrium after a change in explanatory variables.

The results of the bounds test confirm the presence of nonlinear co-integration in the explanatory variables and Pakistan's per capita output growth. Human capital has an asymmetric impact on output growth because of low spending in the education sector. The results reveal that the magnitude of a negative shock is greater than the positive shock of human capital because of the low literacy rate. In Pakistan, several factors are responsible for the low literacy rate, including archaic teaching methods, traditional curricula, staff shortages, poverty, regressive government policies, inaccessibility of schools and low education budgets.

The empirical research considers human capital development a measure of absorptive capacity for foreign technology (Gupta et al., 2022). Unfortunately, Pakistan's knowledge-based learning is inadequate and has hindered the spillover impact of multinational companies on its economic development. The association between technological spillover determinants and economic growth seems asymmetric. However, the magnitude of positive shocks of both determinants is greater than negative shocks, which reveals the relative importance of these factors for promoting growth. The impact of imports of machinery and technological goods is positive on growth in both the short and long run. At the same time, the impact of external R&D capital stock is symmetric in the short run but becomes negative in the long run. Inadequate absorption capabilities and a less-than-threshold level of human capital are responsible for the negative and insignificant effects of international technological knowledge. Furthermore, the CUSUM and CUSUM square graphs confirm the stability of the model over the sample period.

Based on our empirical findings, we suggest that Pakistan must enhance investment in human development by increasing the share of the education sector's budget. The literacy rate and quality of education can only be promoted by upgrading curricula, improving teaching methods and discipline, allocating more funds for education, specifically for skilled education, and ensuring the accessibility of schools for all. Online blended systems of education delivery could be introduced to reap the benefits of modern technology. These measures are essential to achieve an adequate threshold level of human capital. Trade policy should be biased toward capital-intensive imports rather than luxury or consumer goods. Reframing Pakistan's trade policy could help capture the R&D capital stock spillover of developed countries. By investing in proper infrastructure, research environments, incentives and institutions, the domestic R&D capital stock could also be better developed in Pakistan.

Previous efforts to assess the asymmetric relationship between foreign technology-embodied capital imports and domestic technological breakthroughs of advanced trading partners on the economic growth of developing countries have been limited by the unavailability of relevant data. Therefore, the analysis could be extended to panel research by including developing and low-income countries, depending on the availability of the data. Our analysis is also restricted to national productivity because of data availability. It could also be extended to other sectors of the economy, such as the industrial or agricultural sectors, if sector-level data is available. More efforts are required to explore the association and determinants of industrial and agricultural sector productivity, which will likely be a significant future research contribution.

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