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R&D EXPENDITURE AND GROWTH DYNAMICS IN A LOWER-MIDDLE-INCOME AFRICAN ECONOMY: EVIDENCE FROM TUNISIA

Moez El Elj [1]moezelj@yahoo.fr,

Boutheina Abassi[2], boutheinaabassi@yahoo.com

Abstract: *In this paper, we make an original contribution by measuring the impact of R&D capital and knowledge accumulation on economic growth in a lower-medium income African country. For this purpose, we make use of time series data from 1996-2022 and investigate the potential causality relationship between R&D and Economic growth in Tunisia. Using ARDL model, the cointegration analysis suggests that there is a long run relationship between the two factors. However, the R&D returns to growth is relatively weak. Moreover, the results of causality test confirm only unidirectional causality from R&D expenditure to growth. Specifically, when a country experiences relatively low level of growth, no benefits of growth will be directed towards R&D and there is no feedback effect from growth to R&D.*

Keywords: R&D, Economic growth, Cointegration, ARDL estimation

JEL Classification: O30, O47, O11,C23

1Moez El Elj, Senior Lecturer, Higher Institute of Management (ISG), University of Tunis

2 Boutheina Abassi, Lecturer, Private Higher School of Engineering and Technology (ESPRIT).

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1. Introduction

Macroeconomics growth models have emphasized the determinant role of Research and Development (R&D) expenditures as they enhance innovation and productivity growth (Romer 1990; Grossman and Helpman 1991; Griffith et al .2004). Cross-country per capita income differences are omnipresent, and innovation and R&D are among the major reasons: richer countries are the more innovative countries. In fact, disparities of economic growth rate become much more related to the differences in technological capabilities (Easterly and Levin 2001, Prescott 1998).

There is an ample literature on the subject matter: The role of R&D as a contributor to economic growth has been extensively studied particularly in the context of developed and emerging countries. This existing body of literature demonstrates that more R&D activities can lead to the raise of the learning and innovative potential of a country which, in turn, results in an increase of the economic growth level. In spite the fact that numerous studies have been conducted on this topic in the context of developed economies, only few ones examine the potential linkages between R&D activity and long term economic growth for developing countries. In fact, little has been said about the causality relationship between R&D and economic growth for less developed countries. Hence, modeling the relationship between economic growth and R&D remains an interesting area of research, especially for and African developing country like Tunisia.

The Tunisian economy has been involved in a process of economic liberalization and trade openness that has been reinforced with several bilateral agreements with the European Union. Such openness strategy has ensured a steady economic growth during the last decades, giving the country one of the best performances in the MENA region. Growth has been relatively inclusive, and it was sustained at around 4 % annually between 2002 and 2010.Furthermore, Tunisia is considered as one of the typical innovation leaders in Africa. It is characterized by a relatively higher expenditure on education and R&D compared to other African countries. It has an improving research base and an active use of information and communication technologies (ICT's). These make Tunisia relatively well classified in innovation in MENA region with a Global Innovation Index (GII 2020) of 65/131 (World Intellectual Property Organisation WIPO).

However, in spite of these performances, improvement of absorptive capacity and innovation capabilities are relatively weak. As a matter of fact, the promises of the economic integration of innovation was well verified in terms of growth while, impacts in terms of knowledge spillovers and boosting-up innovation performances are very limited. Tunisia is still lagging behind the technological frontier, and the level of R&D in Tunisia is relatively low

(0.6% in GDP) which is far below the EU average. Also, R&D activity has been always dominated by the government and higher education sector (81%) while the business sector's share of the funding of R&D remains quite low (8%).

Since 2011, Tunisia has experienced a phase of transition both on the political and economic levels. Such transition has affected the performances of the Tunisian economy during the post revolution period that was characterized by social, political and economic instability. The economic situation was made worse by the pandemic COVID -19. In fact, the health crisis has considerably affected the Tunisian economy and the economic impacts of this crisis are extremely serious: According to the National Statistics Institute, the Tunisian economy recorded during the whole year of 2020 an unprecedented decline of 8.8% (-8.8%) compared to 2019. These crises have affected the innovation potential of Tunisia: Today, the Tunisian economy still suffers from a limited innovation capabilities, weak R&D institutional framework, and low contribution of private sector to aggregate R&D spending. In 2022, gross expenditure on R&D (GERD) in Tunisia represented approximately **0.61% of GDP**. Private business-enterprise R&D continues to comprise only a minor share (≈ 20%) of total GERD, indicating that the bulk of R&D remains publicly funded.

In recent years, innovation and R&D are characterized by unprecedented progress all over the world. One shall inquire about the importance of knowledge accumulation based on R&D investments to generate and sustain strong economic performance.

This paper's objective is to attempt to contribute to recent advances in our understanding of the source of economic growth in the context of developing countries. The macro approach is applied. We attempt to respond to the question: Does knowledge accumulation through R&D expenditures spur improvement in economic growth in Tunisia?

To the best of our knowledge, the effect of R&D on economic growth is rarely discussed in the context of African countries, and not much empirical contributions have been presented in this area. In the context of developing countries, the existing literature regarding the pro-growth effect of R&D presents mixed and conflicting results (Herzer 2021), and no studies provide conclusive empirical evidence of the effect of both public and private R&D. Thus, the current paper deals with this gap in the literature. This paper aims to estimate the causal relationship and connections that could exist between R&D and economic growth in the context of Tunisian economy. By estimating an augmented production function, we propose to investigate if R&D spending has really contributed to growth in the short term as well as in the long term.

This paper is structured as follow: The next section presents and discusses the existing literature that guides the empirical analysis. The "Hypothesis Development" announces the four major hypotheses on the causality links between R&D and economic growth and presents the results of causality tests. The empirical methodology, including econometric model and data set presentation, is discussed in the "Empirical Methodology" section. The "Empirical Results" section discusses the estimations results and presents concluding remarks.

2. Brief Review of Relevant literature

Endogenous growth theories and innovation-driven growth models (Romer 1990; Grossman and Helpman 1991) have long emphasized the importance of research and development (R&D) and innovation for sustainable economic growth. Much empirical works show that research and development (R&D) is an important contribution to economic growth in developed countries. The evidence to support this expectation for developing countries is, however, rare and far from conclusive.

From an empirical perspective, a number of ad hoc research studies have been conducted to examine the relationships across R&D investment and economic growth. . On the one hand, a strand of literature has found a positive association (Gittleman and Wolff 1995; Pessoa 2010; Genc et al.2010; Nair et al.2020; among others). On the other hand, several studies have reported that, unless certain conditions exist in an economy, the implications of R&D on economic growth are uncertain (Birdsall and Rhee 1993; Inekwe

2015). Accordingly, studies provide evidence of differences in the pro-growth effects of R&D for developed and developing countries. For instance, Lichtenberg (1993) estimated an augmented production function for 74 countries, by introducing a knowledge capital stock and he found a positive relationship between R&D expenditures and productivity growth in the period 1964-1989. He shows that differences in productivity growth between countries are explained by differences in their knowledge capital stocks. Similarly, Guellec et al. (2004) make use of a macro-level aggregate data on 16 OECD countries over the period 1980-98. They found that R&D do matter for economic growth, independently from its source of funds or performing sector, either it is developed by private sector , by the public sector or coming from foreign sources. Hence, the causal relationship between R&D expenditures, innovation and economic growth has been well established in the economic literature especially for developed countries. However, for developing countries, the relationship between R&D and economic growth is still emerging as a controversial subject in the economic literature, especially that the evidence presented so far is rare and inconclusive. These ambiguous results are due, in part, to the problems of data availability and the relatively poor state of R&D data at the national level, especially for African countries.

Some authors tried to examine if public and private R&D spending are relatively important for the ability of developing countries to create steady economic growth. Birdsall and Rhee (1993) attempt to examine the determinants of R&D differentials among countries, using the UNESCO R&D data and found a strong and robust relationship between R&D spending and the level of income. They conclude that R&D could contribute to growth only when the country reaches a certain stage of development. These findings were supported by more recent studies such as the one conducted by Samimi and Alerasoul (2009), using a panel data of 30 developing countries over the period between 2000 and 2006. The authors found no significant effect of R&D expenditures on economic growth using different indicators of R&D such as the share of government R&D spending in GDP, the number of research as well as the number of scientific output. In this line of thinking, Inekwe (2015) considers a sample of developing countries classified according to the income level (upper-middle income countries and lower-middle income countries). The author employs dynamic model estimations, and underlines that the effect of R&D on growth depends on the level of income. A positive and significant relationship between R&D spending and GDP growth are underlined for middle income countries. This effect is weak in the short run but stronger in the long run[1]. However, the pro-growth effect of R&D is insignificant for lower income countries.

The existing literature regarding the effects of public and private R&D on economic growth in the context of developing countries comes with conflicting results, and no studies provide conclusive and clear evidence that both public and private R&D drives growth: the ambiguous results oof the linkages between R&D and growth are partly due to the notable

[1]This finding was also confirmed by Gumus and Celikay (2015) who scrutinize that R&D have different short run and long run effect.

differences between empirical studies that differ in terms of the choice of growth indicators and measurement of R&D, method of analysis, source of data and sample coverage.

3. Hypothesis Development

According to the discussed literature, four hypotheses could be considered to be relevant in describing R&D growth connectivity.

The first hypothesis is **the Growth Hypothesis**: This hypothesis pinpoints R&D investment as a vital factor for economic growth. The hypothesis explains how R&D capital stocks and R&D accumulation got a positive impact on GDP. In fact; R&D expenditure has a positive and significant effect on economic growth. This effect is usually weak in the short-run but stronger in the long-run (Lichtenberg 1992; Guellec el.2004; Pessoa 2010; Genc et al.2010; Gumus and Celikay 2015…).

The second hypothesis is **the Conservation hypothesis**: The conservation hypothesis suggests a scenario where there is a unidirectional causality emanating from economic growth to R&D. It means that there is a unidirectional causality from economic growth to R&D: increased economic growth means increased R&D investment (Birdsall and Rhee; 1993). High level of R&D expenditure requires a certain level of development.

The third hypothesis is **the Feedback hypothesis** which implies bi-directional causality i.e.; R&D and economic growth has a symbiotic relationship. In fact; there is a two-way causality relationship between R&D activities and GDP levels in the long-run (Wu et al. 2007; Guloglu and Tekin 2012…). More R&D contributes to growth; but to strengthen this effect it is important that the benefits of growth will also be directed towards R&D and the accumulation of knowledge.

The last hypothesis **is the Neutrality hypothesis** that negates any kind of relationship between growth and R&D and thus, considers them as independent factors (Pessoa 2007…).

The aim of our study is to validate and verify the relevance of these four hypotheses in the context of the Tunisian economy—a developing country that has little attention in the literature. Therefore, the relationship between GDP level and R&D expenditure is examined using annual data for the1996-2022periods. The data was taken from the World Bank Indicators Data and the UNESCO database. Table 1 shows the variables used in the study and the basic model.

Table1: Variable and Basic Model description

$\ln(GDP_t) = \alpha_t + \ln(GERD_t) + \varepsilon_t$			
Variable	**Designation**	**Source**	**Period**
GDP	The level of income, USD	World Bank	1996-2022
GERD	R&D spending ,USD	World Bank	1996-2022

We investigate the causality relationship between R&D expenditures and GDP, by considering the linear regressions models described above:

$$\ln(GDP)_t = \alpha_0 + \alpha_1 \ln(GERD) + \varepsilon_t$$
$$\ln(GERD)_t = \beta_0 + \beta_1 \ln(GDP) + \varepsilon_t$$

One major assumption of causality analysis is the stationarity of the time series. Hence, the stationarity of the variables (GDP and GERD) is investigated using the most common tests that are, Augmented Dickey-Fuller (ADF, 1979) and Phillips-Perron (PP, 1988)2 unit root tests. The results of both tests are presented in Table 2.Both unit root tests show that GDP is I (0) and GERD is I (1).

Table 2: Panel unit root tests

Variable	Description	Constant		ADF test (First difference)	Order of Integration
		ADF	P.P		
GDP	*Gross domestic Product*	-3.548**	-3.606***	-	I(0)
GERD	*Gross expenditure on R&D*	-1.378	-2.095 ***	-3.606 ***	I(1)

Toda and Yamamoto (1995) proposed a simple approach based on estimating a modified VAR (k + dmax) model in order to investigate causality (where dmax is the maximal order of integration for the series and (k) and the maximum order of integration). In our cases dmax=1 and k is determined using the AIC criteria. Unlike Granger causality test, Toda and Yamamoto

[2]ADF test and Phillips-Perron tests the null hypothesis (H0: Serial has a unit root so it is not stationary) versus the alternative one (H1: Serial has no unit root so it is stationary).

causality test (1995) is less sensitive to lag order selection and the level of integration of the time series.

Table 3: Toda-Yamamoto Causality Test Results

		test for GDP Granger–causality to GERD		test for GERD –causality to GDP	
k	*d*	$GDP \rightarrow \boldsymbol{GERD}$		$GERD \rightarrow \boldsymbol{GDP}$	
		Wald Statistic	*p-value*	*Wald Statistic*	*p-value*
5	1	7.97	0.240	29.30	0.000***

The results presented in Table 3 confirm the existence of unidirectional causality from R&D expenditure to growth but not causality from growth to R&D: *Validation of the Growth Hypothesis*. This result shows that the increase in R&D spending leads to higher growth level, especially during the pre-revolution period. However, there is an absence of a feedback effect and the growth spillovers experienced by the Tunisian economy were not efficiently allocated. The country has not succeeded to capitalize growth externalities to promote R&D activities and to increase knowledge capital accumulation.

4. Empirical Model

To compute the R&D contribution to productivity growth, we propose an extended production function in line with Lichtenberg (1993) and Birsdall and Rhee (1993):

$$\boldsymbol{Y_{(t)} = A_t RD_t^{\gamma} K_t^{\alpha} L_t^{\beta}} \quad \textbf{(1)}$$

In this production function, the stock of R&D capital is included together with traditional production factors (physical capital K and employment L). Further details on variables construction are presented in Appendix A (Table A1). The level of growth is a linear function of physical capital stocks, employment rate as well as R&D capital stocks, which could be deduced from the following logarithmic transformation.

$$\boldsymbol{gdp_t = \alpha_0 + \alpha_1 k_t + \alpha_2 l_t + \alpha_3 krd_t + \alpha_k Schooling + \varepsilon_t (2)}$$

Where, gdp, k, l, krd are the respective logarithm of GDP, K, L and KRD.

Physical capital stock and R&D capital stocks are constructed using the perpetual inventory method (Appendix A2).

Moreover, additional controls variables could be include in the model. The choice of these control variables depends on data availability. So far, tertiary enrollment is included in the model as control variable.

In order to examine the relationship between economic growth and R&D, the methodology adopted is the autoregressive distributed lag (ARDL) approach [3] (or bounds testing cointegration procedure), proposed by Pesaran et al. (2001).

ARDL models are part of dynamic models, which are suitable for estimating short-term dynamics and long-term effects for co-integrated series and even, integrated ones with different orders of integration. The ARDL approach is based on the assumption that the variables are I (0) or I (1) ,and allows for both stationary and non-stationary repressors. The existence of a long-run /cointegration relationship can be tested based on the EC representation and using bounds testing procedure (Pesaran, Shin, and Smith, 2001). Furthermore, the ARDL method estimates the long and short-run components simultaneously, avoiding issues associated with omitted variables and autocorrelation. Thus, estimates obtained from ARDL approach are unbiased and efficient.

Hence, Equation 2 could be represented as an unrestricted error correction model (ECM) and Equation (3) indicates that economic growth is explained by its past value and the past values of the explanatory variables.

$$\Delta(GDP)_t = \alpha_0 + \sum_{i=0}^{p} \beta_i \Delta(K)_{t-i} + \sum_{i=0}^{q} \gamma_i \Delta(L)_{t-i} + \sum_{i=1}^{r} \theta_i \Delta(KRD)_{t-i} + \sum_{i=0}^{s} \lambda_i \Delta(Schooling)_{t-i} + \delta_1 GDP_{t-1} + \delta_2 K_{t-1} + \delta_3 L_{t-1} + \delta_4 KRD_{t-1} + \delta_5 Schooling_{t-1} + \mu_t \quad (3)$$

Where, Δ : the first-difference operator and u_t is assumed to be normally distributed and white noise.

[3] The ARDL estimation approach or bounds testing integration procedure is proposed by Pesaran et al.(2001)

Equation (3) also can be considered as an ARDL of order (p, q, r, s), where p, q, rand s are the order of lags length of gdp, k, l and krd, respectively.As with any dynamic model, we use information criteria (of Akaike (AIC), Schwarz (SIC), Hannan and Quinn (HQ)) to determine the optimal lag. An optimal lag is the one whose estimated model offers the minimum value of one of the stated criteria.

We examine the (non-) stationarity of the variables by applying the general model formulation, with a constant included. If the null hypothesis of unit root (no stationarity) is not rejected and the variable is integrated with order 1, we then apply first differentiation. The results of unit root tests are presented in Table 4.

Table 4: Stationarity Tests (Augmented Dicker Fuller test ADF and Phillips-Perron P.P)

Variable	Description	Constant		ADF test (First difference)	Order of Integration
		ADF	P.P		
Log(GDP)	*Gross domestic Product*	-3.548**	-3.606***	-	**I(0)**
Log(K)	*Physical capital stock*	-0.123	-0.153	-3.045**	**I(1)**
Log(L)	*Labour*	-1.825	-2.305	-3.002**	**I(1)**
Log(KRD)	*R&D capital stock*	-3.771***	-2.399	-	**I(0)**
Schooling	*Tertiary Enrollment (%)*	-3.313***	-3.131***	-	**I(0)**
Test statistics values (%5)		**-3.000**	**-3.000**	**-3.000**	

Notes: Maximum lag length is considered as five and determined according to Schwarz Information Criteria. ADF test and P.P test statistics values for constant model are as follows: -3.75 (%1), -3.00 (%5) and -2.63 (%10). The figures which is ***, ** and * show 1%, 5% and 10% levels, respectively.

5. Results and Discussion

Both unit root tests (ADF Test and Phillips-Perron tests) demonstrate that some series are stationary at level or at first difference. In fact, GDP, R&D capital and schooling are stationary at level, whereas physical capital and labor are stationary at first differences. As all series are mix of I (0) and I (1), short run and long run dynamics are estimated using ARDL method of cointegration analysis. We use the Akaike Information Criterion (AIC) to select the optimal number of lags for the ARDL model to provide statistically significant results. Also, we conduct bounding cointegration test to verify the existence of a long-run relationship between GDP level and its determinants. If the computed F-statistic is smaller than the lower bound value, then the null hypothesis is accepted, thus, there is no long-run relationship between GDP and its determinants. On the contrary, if the computed F-statistic is greater than the upper bound value, then GDP level and its determinants share a long-run level relationship. On the other hand, if the computed F-statistic falls between the lower and upper bound values, then the results are indecisive.

The F-statistic for co-integration analysis for the selected ARDL model is reported in **Table 5**. The results of the bounds cointegration test support the precondition of co-integration and confirm the existence of long-run relationship between the series since the statistic of F is higher than that of the upper bound.

Table 5: Results of the Pesaran Cointegration Test

Dependent variable: GDP

Specification	F-statistics	Lower Bound (5% threshold)	Upper Bound (5% threshold)	Conclusion
(GDP/K,L,KRD, Schooling)	5.570	3.52	5.06	Presence Cointegration

Table 6 depicts short-run and long run-dynamics. Numerous tests are used to check the robustness of the model. These tests are presented in Table 6. Breusch- Godfrey serial correlation LM test shows that there is no serial correlation. Jacque-Bera normality test shows that the residuals are normally distributed and Breusch-Pagan-Godfrey test confirms the absence of heteroscedasticity problem.

The results show that GDP seems to have lagged impact on itself and error correction term is negative and statistically significant at 1% level. The error correction term amounts to 0.58, which indicates that the speed of adjustment to the steady state is relatively high .The estimated coefficient associated to labour (L), physical capital stock (K) and the rate of tertiary enrollment (Schooling) have the expected signs and are positive and significant, confirming the contribution of traditional production factors to the economic growth in Tunisia.

The estimation results provide also short and long run relationship characterization of the R&D returns in terms of growth. Empirical findings reveal both short and long run effect of R&D capital stocks on economic growth in Tunisia. In the short run, an increase of R&D capital stocks by 1% leads to an increase of output by 0.09%. Also, steady-state long-run relationship among R&D and economic growth is well established. In fact, the accumulation of R&D boosts growth by 0.16%. This implies that an increase in R&D generate a beneficial impact on economic growth and. R&D spending has different short and long run effects on growth. This result indicates that the effect of R&D is weak in the short run, but relatively stronger in the long run, which comes in line with previous studies in the context of developing countries.

Table 6: ARDL estimation results

Short-run relationship

	Coefficient	t-statistics	p-value
Adjustment coefficient			
gdp t-1(L1.gdp)	-0.584**	-3.69	0.004
Δ k $_t$	0.760*	2.00	0.071
Δ k $_{t-1}$	-0.850**	-2.28	0.043
Δ l $_t$	0.566**	2.64	0.023
Δ krd $_t$	0.096**	2.26	0.045
Δ Schooling $_t$	0.139**	2.52	0.029
Constant	4.565**	4.62	0.001

Long-run relationship

	Coefficient	t-statistics	p-value
k $_{t-1}$ **(L1.k)**	0.081	0.53	0.606
L$_{t-1}$ **(L1.l)**	1.414***	4.39	0.001
krd $_{t-1}$ **(L1.krd)**	0.164*	1.86	0.090
Schooling $_{t-1}$ **(L1.Schooling)**	-0.058	-0.87	0.403

***, ** and * indicate significance at 0.01, 0.05 and 0.10 level respectively.

Model criteria / Goodness of Fit:

R-square = 0.94; Adjusted R-square = 0.89

Diagnostic Checking:

JB = 1.13[0.596]; Breusch-Godfrey Serial Correlation LM Test: 1.788[0.516 Heteroskedasticity Test: Breusch-Pagan-Godfrey: 0.68[0.411].

The lag order is selected by Akaike's Information Criterion (AIC).

However, it is worth to mention that the R&D returns to growth in the Tunisian economy is relatively weak. Indeed, for developed countries, the elasticity of R&D with respect to GDP is significant and ranges from 0.32 for countries like Portugal to 1 for the United Kingdom and France. However, for developing countries, the evidence provided by subsequent work shows that R&D returns is significantly lower than those recorded for more developed countries (Table 7). For example, in an empirical study conducted for a panel of developing countries, Inekwe (2015) found that the long-term effect of R&D on economic growth amounts to almost 0.46%. This holds true particularly of upper-middle income countries while for lower-income countries the coefficient associated to R&D is either negative or insignificant.

Table 7: R&D returns: the impact of R&D on economic growth

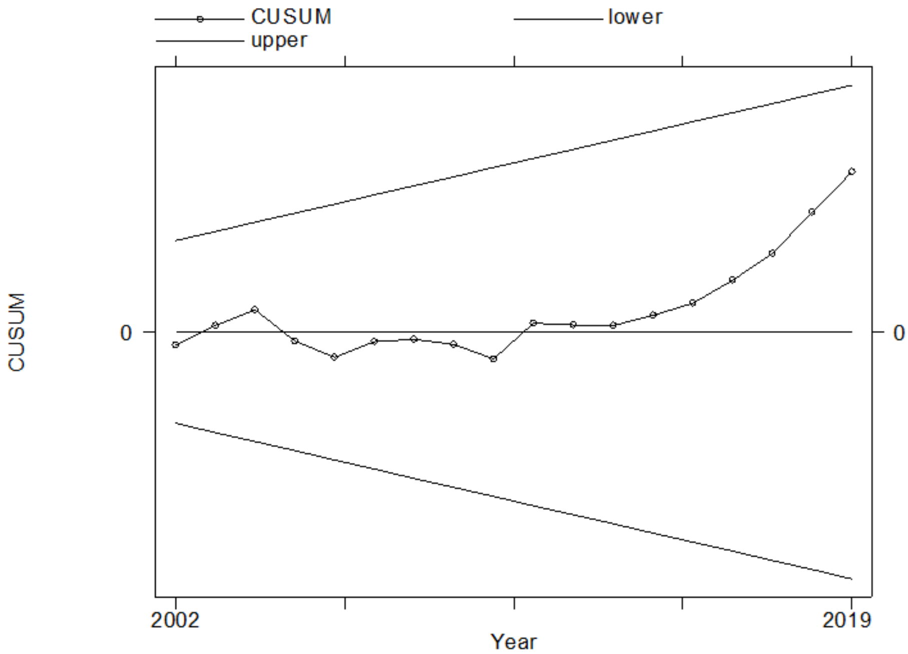
Developed Countries*	
Country	R&D elasticity
United Kingdom	1.18
France	1.04
USA	0.88
Japan	0.80
Austria	0.473
Finland	0.537
Portugal	0.322
Developing countries	
Country	R&D elasticity
Turkey *	0.625
Upper-middle income countries**	

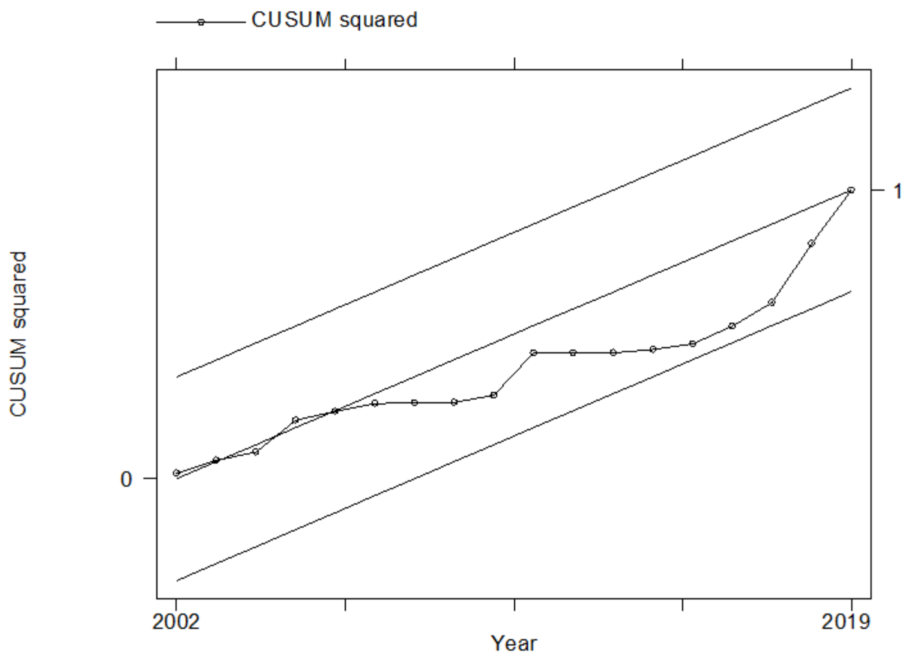
South Africa Morocco Jordan Egypt	0.22 % to 0.46%	up

Source:* Akcali and Sismanoglu (2015: period of analysis 1990-2013)
**Inekwe (2015: period of analysis 2000-2009)

Structural stability of short-run and long-run coefficients is verified by examining the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of recursive residuals squares (CUSUMSQ). The CUSUM test is based on first set of n observations. It is updated recursively and is plotted against the break points. If the plots of CUSUM statistics stay within the critical bounds of 5% level of significance, then it means that all coefficients are stable and consistent (Pesaran and Pesaran 1997). The CUSUM plot to check the stability of short run and long run coefficients in the ARDL error correction model are given below in **Figure 1**. It shows that statistics CUSUM and CUSUMSQ are within the critical bounds, confirming the structural stability of our model.

Figure 1: Structural stability test: CUSUM and CUSUM of square tests.





Conclusion and Recommendations

This study analysed the long-run impact of aggregate R&D on economic growth in Tunisia over the period 1996–2022. The results show a mixed but instructive picture for an upper-middle-income African economy. On the one hand, Tunisia's innovation system remains constrained by persistent structural weaknesses, including low overall R&D intensity, the predominance of publicly funded research, and the limited engagement of the business sector in R&D activities. These limitations have restricted the country's capacity to benefit fully from global technological dynamics. On the other hand, despite these constraints, our empirical evidence confirms that R&D accumulation exerts a **positive and statistically significant** long-run effect on GDP growth. Nevertheless, the size of this elasticity is modest when benchmarked against comparable economies. Furthermore, the Toda–Yamamoto causality test identifies a **unidirectional causal relationship** running from R&D capital to economic growth, indicating that economic expansion does not sufficiently feed back into additional R&D investment. This finding suggests that the Tunisian economy has not yet developed an efficient mechanism for reinvesting growth spillovers into knowledge creation and innovation.

These results carry important policy implications for Tunisia and, more broadly, for African economies seeking to enhance their innovation capacity. First, there is a clear need to **rebalance the national R&D structure** by strengthening private-sector engagement. Incentives such as tax credits, innovation grants, risk-sharing mechanisms, and improved access to early-stage finance could help stimulate business R&D, particularly in high-potential technological sectors. Second, improving the **governance and efficiency of public R&D** is essential. This includes better strategic targeting of research priorities, performance-based evaluation, and stronger alignment between public research outputs and national development needs. Third, more effective **technology transfer and university–industry collaboration** are needed to ensure that knowledge generated in public institutions translates into marketable products, productivity gains, and new entrepreneurial opportunities. Innovation clusters, incubators, and collaborative R&D programmes can play a central role in achieving this objective.

Looking ahead, the increasing importance of **Artificial Intelligence (AI)** presents an opportunity for Tunisia to modernise its growth model. Including AI as an additional input in an expanded production function—alongside labour, physical capital and R&D—may generate new productivity gains and accelerate innovation diffusion. AI has the potential to strengthen traditional sectors such as agriculture, manufacturing, and services, while also enhancing public-sector efficiency. Realising these gains, however, requires investment in digital infrastructure, the development of AI-related skills, improved data governance, and an enabling regulatory environment that encourages technological adoption.

Overall, while Tunisia's innovation system continues to face structural challenges, the evidence presented in this study confirms that R&D remains a key driver of long-term economic performance. A policy mix that combines stronger private-sector participation, improved public research governance, more effective technology transfer mechanisms, and the strategic integration of AI can significantly enhance the growth-enhancing effects of R&D. Such reforms would not only strengthen Tunisia's long-term development trajectory but may also provide useful lessons for other African economies striving to build competitive and innovation-driven growth models.

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Appendices:

Appendix A

Table A1: Variable Description

Variables	Description	Designation	Data Source
Level of Economic growth	GDP (Data are in constant 2010 US$)	**GDP**	World Bank Indicators (World Bank national accounts data)
Investment	Gross fixed capital formation (deflated using GDP deflator*)	**GFCF**	World Bank Indicators (World Bank national accounts data)
Physical capital stock	Accumulated stock of physical capital calculated using the perpetual inventory method	**K**	Authors' own calculations
Labour	Employment (Thousands) comprise all persons of working age who are in one of the following categories: paid employment or self-employment	**L**	World Bank Indicators (World Bank national accounts data)
Gross R&D expenditures	Gross domestic expenditures on research and development R&D (deflated using GDP deflator*)	**GERD**	UNESCO Institute for Statistics
Capital R&D stock	Capital R&D stocks (calculated using perpetual inventory method)	**KRD**	Authors' own calculations
Schooling Tertiary	School enrollment, tertiary (% gross enrollment)	**Schooling**	World Bank Indicators (World Bank national accounts data)

* 2010 reference year

A2: Construction of physical capital stock and R&D capital Stock:

Empirical literature of economic growth has proposed a unified approach which is the perpetual inventory method (PIM). This method is frequently used for the construction of capital stocks. The fundamental idea of the PIM is to consider the capital stocks as inventory that increase with capital formation or investment. This approach is used to construct both physical capital stocks and R&D capital stocks:

K_t: physical capital stocks

$$K_t = (1 - \delta) * K_{t-1} + GFCF_{t-1}$$

WithGFCF represent gross fixed capital formation and initial physical capital stocks as follow:

$$K_{t=0} = \frac{GFCF_{t=1}}{g + \delta}$$

With,

$GFCF_{t=1}$ is the amount of GFCF at the first year of period, g presents the rate of growth of capital investment, and δ is the depreciation rate of capital stock.

The same approach was used to create R&D capital stocks:

$$KRD_t = (1 - \delta) * KRD_{t-1} + RD_{t-1}$$

According to common practices in the literature, the depreciation rate is 15%.

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