ICT, trade openness and economic growth in Tunisia: what is going wrong?

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Abstract

In the age of digital globalization, information and communication technologies (ICT) and international trade seem to have become the engines of economic growth. In this study, we investigate the impacts on Tunisia's economic growth of using ICTs and greater trade openness. We employ a cross-section augmented autoregressive distributed lag (CS-ARDL) model and apply Dumitrescu and Hurlin Granger causality test to panel data for 14 economic sectors in the period 1995–2018. The empirical findings suggest that use of ICTs has a long-term relationship with value added and increased economic growth in Tunisia. In addition, trade openness and gross fixed capital formation (GFCF) have a positive and significant effect on economic growth. We also examine the relationships among these variables in the short and long run. The Dumitrescu and Hurlin test reveals four bidirectional and two unidirectional causal relationships between the variables.

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1 Introduction

Economic growth is important for achieving economic and social development which are major national objectives. How to achieve maximum levels of welfare and improve competitiveness and economic growth have been the topics of a large body of political and scientific research.

Analyzing economic growth and its determinants is important for all economies and especially less developed countries and is critical in times of economic crisis such as those triggered by the COVID-19 pandemic. In this context, we need to pay attention to the importance of efficiency to achieve growth, and the productivity of internal activities such as innovation and job creation which are fundamental for achieving competitive advantage to promote sectoral growth and market dominance.

In this context, we need to focus on the factors which influence value-added growth such as gross fixed capital formation (GFCF), trade openness and the use of information and communication technologies (ICTs) to understand the national economic reality and formulate strategies to enable future economic development.

The role of trade openness in stimulating economic development has been the topic of research since at least the 1950s (Huchet-Bourdon et al. 2018). Carnevali et al. (2020) highlight the work of economists such as Smith, Kalecki, Kaldor, Ricardo and Thirwall among others, which emphasizes that trade between the countries allows intensification of production levels and increased income. Similarly, Toader et al. (2018) highlight the importance of international trade, both export and import, to facilitate economic expansion.

Likewise, Zaman et al. (2021) consider that trade openness and GFCF are significant in terms of identifying the level of income derived from exports and the capital outflows related to imports. They evaluate national trade competitiveness at the international level.

The theoretical and empirical literature emphasizes the increasingly major role played by technological innovation particularly ICTs which are considered general purpose technologies (GPTs), for improving sectoral productivity and accelerating economic growth. Innovative ICTs are considered radical innovations. Their introduction as GPTs has brought several technological and organizational changes in a wide range of activities (Antonelli 2017). According to Mickoleit et al. (2009), the diffusion of ICT throughout the economy is providing opportunities for productivity improvements by firms, and public and social institutions and the development of new products and services which are boosting multifactor productivity.

This points to the importance of up-to-date knowledge on the effects of those factors that can lead to economic growth and development. The present work analyzes the impact of these factors in the context of the Tunisian economy based on three input Cobb–Douglas production functions, to understand Tunisian economic growth and the elasticities of its components.

This study makes at least two contributions to the specialized literature on the impacts of ICTs on economic growth. First, it extends it by decomposing

new OECD input–output data to construct an ICT diffusion index and uses the dynamic common correlated effects modeling technique for panel data proposed initially by Chudik et al. (2016) and developed further by Ditzen (2018) to perform the sectoral analysis. Second, our use of cross-sectoral data in the context of Tunisia is quite rare. Section 2 introduces the theoretical framework and discusses the relevant literature. Section 3 presents the data and the analyzed variables and describes the empirical methodology. Section 4 presents the results and draws some conclusions.

2 Theoretical framework

The development of ICTs and the innovations they facilitate have increased economic performance. Schumpeter (1942) discusses different types of innovations and suggests that they may be new products, new combinations or new markets. One characteristic of ICT is the ability to generate interactions which improve productivity. Their synergistic effects can affect the whole knowledge-based economy and lead to the production of new knowledge and greater productivity. Their temporal and spatial characteristics enable the rapid diffusion of knowledge and innovation to the productive sector. Thus, heavy investment by the developed countries in ICTs especially in productive sectors, has favored the transition to a global knowledge-based economy (Fukuda 2020). ICTs are one of the determinants of current production, and are increasing efficiency and productivity in a range of different sectors. Thus, economic performance, overall competitiveness and economic development depend largely on availability, adoption and use of ICTs (Toader et al. 2018).

Some authors (Frank et al. 2019; Park 2018; Vu et al. 2020) compare the ICT revolution to the first industrial revolution and the changes triggered by electricity and steam power. The United Nations defines ICTs as GPTs which promote power systems (Bresnahan and Trajtenberg 1995). The wide-ranging effects of ICTs both economically and socially have led to the emergence of a new paradigm based on intensive use of information and knowledge. In today's economies, ICTs are affecting almost all economic sectors, opening new economic opportunities, enabling entrepreneurial initiatives, and generating innovation and knowledge spillovers (Taalbi 2019). They are also enabling complementary innovations, thereby generating economic growth (Czernich et al. 2011).

Other strands of work focus on the relationship between ICTs and economic growth from two different perspectives. One stream of work examines the relationship between ICTs and economic growth using exogenous growth models. The second stream examines this relationship based on endogenous growth theory. In both cases, technological change is important for economic growth (Fernandez-Portillo et al. 2020).

The results in the literature differ depending on the country or group of countries studied, the time periods considered and the methods applied. In addition, the determinants differ between developed and developing countries and in the former the impact of ICTs on economic development is more pronounced than in the latter. Due to lack of data for the developing countries, most studies focus developed regions.

However, the empirical literature provides mixed results for the effects of ICTs on economic growth. Some studies find a significant positive impact of ICTs on economic growth (Njoh 2018; Adeleye and Eboagu 2019; Ben Lahouel et al. 2021; Jorgenson and Vu 2016; Kallal et al. 2021; Niebel 2018; Sassi and Goaied 2013; Haftu 2019; Jung and Lopez-Bazo 2020; Toader et al. 2018; Vu 2011; Vu et al. 2020; Samimi and Arab 2011), others find a negative relationship of ICTs on economic growth (Bertschek et al. 2013; Ejemeyovwi and Osabuohien 2020; Haller and Lyons 2015; Ishida 2015; Mayer et al. 2020; Thompson and Garbacz 2011). It should be noted also that the impact of ICTs on economic growth is not homogeneous across countries (Mayer et al. 2020). In particular, developing countries are at a competitive disadvantage which serves to increase the dominance of the developed countries in a global context. ICTs provide opportunities for the developed countries to open up to and attract new markets which provides them with a relative advantage. Developing countries are not only less competitive in the international market but also are threatened in their domestic markets. Therefore, use of ICTs can delay catch up by the developing countries and increase the gap between the developed and developing countries. ICT also can have negative impacts on the income distribution in developing countries; it is more difficult for low-income developing countries to acquire the equipment they need to benefit from ICTs due to the high cost of access compared with the developed and high-income countries.

In the Tunisian case, Ben Lahouel et al. (2021) investigated the effect of ICTs on economic growth during the period 1970–2018 using a smooth transition regression and found that ICT investments contributed to economic growth. However, Kallal et al. (2021) used a panel pooled mean group form of the autoregressive distributed lag model for the period 1997–2015 in Tunisia and found that ICT had a positive long-term effect on economic growth but a negative short-term effect. Similarly, Naanaa and Sellaouti (2017) investigated the effects of technological change on growth based on an analysis of technology spillovers and their channels of transmission in five Tunisian manufacturing sectors during the period 1970–2012. In addition to showing that manufacturing sectors benefit from foreign direct investment only after a certain ICT development threshold, the authors suggest also that Tunisia should strengthen its ICT infrastructure. The positive impact of ICTs on economic growth was highlighted also by Saidi et al. (2015) who analyze the relationship between the rate of growth of GDP and the index of ICT use for Tunisia during 1975–2008. Nevertheless, we lack a good understanding of the overall contribution of ICTs to sectoral value added in Tunisia, and most sectoral analyses are biased because they fail to count for cross-sectoral heterogeneity and cross-sectoral dependence.

Another factor that can affect national economic development is degree of trade openness. First, it allows local producers to benefit from better quality imported intermediate products when domestic production is absent or weak, and to exploit ideas triggered by imports of innovative products including ICTs. Second, trade openness increases competition which in turn works to increase productivity, efficiency and innovative capacity among domestic producers (Huchet-Bourdon et al. 2018). However, the applied literature on the relationship between trade openness and economic growth does not find such a strong positive relationship (Hamel

Breghish and Neama Ali 2021; Musila and Yiheyis 2015; Trejos and Barboza 2015; Carnevali et al. 2020; Huchet-Bourdon et al. 2018; Idris et al. 2017; Toader et al. 2018; Zaman et al. 2021).

ICT developments are have effects also on global trade. The gradual digitalization of economic processes has led to a restructuring of economic activities and the idea of the digital economy. From this perspective, application of internet-based digital technologies to the production of and trade in goods and services has become important for the international economy. By reducing the costs incurred by buyers for obtaining information on sellers' prices and product offerings, ICTs are making markets more transparent. Toader et al. (2018) suggest that use of ICTs is influencing economic growth indirectly through greater trade openness.

3 Methodology

3.1 Data and preliminary analysis

The annual data for the period 1995–2018 were extracted from the 2021 edition of the OECD Input–Output tables. Our analysis includes 14 economic sectors based on the International Standard Industrial Classification (ISIC) Rev. 4 of economic activities.

Trade openness (TO) is measured as the sum of the sector's exports and imports of goods and services divided by the sector value added (VA). The ICT diffusion index (IDI) captures the degree of ICT diffusion across all economic sectors and determines the share of ICT in the VA of a particular sector. The IDI provides policymakers with a simple and easy-to-use tool to assess diffusion of ICTs and better understand the specific challenges associated with their deployment to inform economic development strategies appropriate for that domain. Technically, the IDI is based on an input–output analysis (Leontief 1986) to assess sectoral economic performance and the interdependence between production and consumption in a specific economy (Mustafin and Kantarbayeva 2018; Suh and Lee 2017). In this latter approach, there is close interaction among the industries in an economy which produce a single type of commodity (output) and consume the goods or services produced by other industries (intermediate inputs) to achieve that output. As reported by Miller and Blair (2009), the rows in the input–output table present the total intermediate supply values for each sector and represent the horizontal demand side of the Leontief model. The goods and services produced may be consumed by other sectors as intermediate products or consumed by households or government as final products. The columns in the table present the supply side and describe the composition of the inputs required by a particular industry to produce its output.

Similar to the approach based on the demand-side model in Suh and Lee (2017), IDI is calculated by dividing the intermediate input of ICTs to sector j by the total input of sector i, as follows:

$$IDI = \left(\frac{x_{ij}}{x_{i\bullet}}\right),$$

where i and $j = 14$ productive sectors.

The ICT sector is defined by the OECD (2009) as combining "*all economic activities that contribute to the visualization, processing, storage and transmission of information electronically*" and is classified according to the ISIC Rev.4 (United Nations 2008). It includes several industries:

(1) ICT manufacturing industries (manufacture of electronic components and boards, computers and peripheral equipment communication equipment and magnetic and optical media),
(2) ICT trade industries (wholesalers of computers, computer peripheral equipment, software, electronic and telecommunications equipment and parts),
(3) ICT services industries (software publishing, telecommunications, computer programming, consultancy and related activities, data processing, hosting and related activities; web portals, repair of computers and communication equipment).

Figure 1 depicts diffusion of ICTs in various Tunisian economic sectors over the period 1995–2018. We observe that the share of ICTs in total intermediate consumption varies across sectors of activity. While integration of ICTs is comparatively low (less than 5%) in most sectors, it is relatively high in *S10: Information and communication* (32.62% over the whole period), *S11: Financial and insurance activities* (21.31%), *S13: Professional, scientific and technical activities* (18.34%), *S14: Public administration* (15.38%), and *S7: Wholesale and retail trade* (11.84%).

3.2 Model construction

The theoretical framework used to assess the influence of ICTs and trade openness on economic growth is the model proposed by Solow (1956) and extended by Mankiw et al. (1992). The production function can be rewritten as

$$Y_{it} = A_t F(X_{kit}^{\alpha_k}) \text{ with } 0 < \alpha_k < 1,$$

where Y_{it} is VA, X_{it} is a vector of the explanatory variables, A_t is technological progress and α_k are elasticities.

This functional relationship can be specified as a Cobb–Douglas production function:

$$Y_{it} = A_t \prod_{k=1}^{K} X_{kit}^{\alpha_k} \text{ with } 0 < \alpha_k < 1.$$

We apply the natural logarithm to rewrite the linearized equation as follows:

S1

1995-2018: **0.7%**

S2

1995-2018: **5.7%**

S3

1995-2018: **3.0%**

S4

1995-2018: **4.4%**

S5

1995-2018: **3.1%**

S6

1995-2018: **3.3%**

S7

1995-2018: **11.8%**

S8

1995-2018: **6.0%**

S9

1995-2018: **1.9%**

S10

1995-2018: **32.6%**

S11

1995-2018: **21.3%**

S12

1995-2018: **9.3%**

S13

1995-2018: **18.3%**

S14

1995-2018: **15.4%**

Fig. 1 Diffusion of ICTs in Tunisia's economic sectors

$$Ln(Y_{it}) = Ln(A_t) + \sum_{k=1}^{K} \alpha_k Ln(X_{kit}),$$

where *i* is 14 sectors, *t* is the time period and *k* is the three explanatory variables.

3.3 Econometric methodology

This study investigates the effect on economic growth (*LVA*) of ICTs (*LIDI*) and trade openness (*LTO*) in the presence of investment (*LGFCF*) using advanced econometric procedures. First, we test the assumption of homogeneity of the regression slopes and second check for cross-section dependence (CD) in panel. Third, we employ a panel cointegration test to check for correlation over the long term. Fourth, we use an econometric model and estimation approach based on the results of the previous tests to enable analysis of the long-run causal relationships among the variables.

3.3.1 Test for slope homogeneity

For the econometric estimation using panel data, we need to identify the nature of the slopes. To test the homogeneity of the slopes, we run the Pesaran and Yamagata (2008) test which is based on the dispersion of each individual weighted slope. The Monte-Carlo simulations show that the test is appropriate for small sample sizes and dynamic and unbalanced panel data.

3.3.2 Test for cross-section dependence

To check for potential common correlation effects among the variables, we use the CD test. Baltagi et al. (2007) warn that ignoring common correlation effects in panel data can affect the estimation results. Pesaran's (2015) CD test outperforms other tests due to its applicability to different variable lengths.

3.3.3 Panel unit root test

This step involves performing a test to determine the order of integration of the different variables. The existence of CD for all the variables confirmed by Pesaran's (2015) CD test implies potentially biased results by a first-generation unit root test. Given the CD of the errors and the slope heterogeneity, we use the second-generation panel unit root test (Pesaran's 2003 CADF, and Pesaran's 2007 CIPS). According to Baltagi et al. (2007), the CIPS test is more robust in the presence of various sources of CD including spatial or geographic proximity. Baltagi et al. (2007) examined the relative performance of several panel unit root tests in the presence of CD and found that the main attribute of this type of test is that it allows for CD, a concrete possibility overlooked in the empirical panel data literature.

3.3.4 Panel cointegration test

After identifying the degrees of integration of the variables, we test whether there are cointegration relationships between the non-stationary components of the data series. Cointegration tests are used widely in econometrics. The objective is to test for the existence or not of a linear combination between the stationary variables in levels and in first differences. Examining cointegration makes it possible to test for the existence

of a long-term equilibrium relationship among the variables considered. Before 2010, cointegration was tested based on first-generation panel cointegration tests, which assume cross-sectional independence.

The first set of cointegration tests known as the first-generation panel cointegration tests includes the tests developed by Kao (1999) and Pedroni (1999, 2001, 2004) which deal with the problem of heterogeneity among different panel members. The existence of CD in the data means that the results of Pedroni and Kao's cointegration tests may not be robust.

Westerlund (2007) developed an error correction-based panel cointegration test which is robust in the presence of the CD.

The second group of cointegration tests account for possible CD in the data. In the next step, we test the long-run relationship among the variables using two panel cointegration tests by Westerlund (2007) and Pedroni (2004).

3.3.5 Dumitrescu and Hurlin causality test

We employ a dynamic Granger non-causality test based on the method proposed by Dumitrescu and Hurlin (2012) to check the robustness of our econometric results. While this test assumes that the coefficients differ across cross-sections, the standard Granger test assumes that all coefficients are similar for all individuals in the panel.

Dumitrescu and Hurlin's (2012) test combines cross-sectional and time series data which give it particular power. It accounts also for country heterogeneity due to economic, political, structural, or institutional particularities. The test estimates individual Granger causality for each cross-section and calculates the average of the individual tests considering a statistical significance ($\overline{W}$ statistical) and a standardized statistic $\overline{W}$ —the $\overline{Z}$ statistic. In this case, the null hypothesis y does not homogeneously cause x, and vice versa.

3.3.6 Model specification

In this theoretical framework, we can use a cross-section auto regressive distributed lag (CS-ARDL) modeling approach to analyze the effect of our explanatory variables on economic growth. To estimate our model, we employ the panel data procedure for the dynamic common correlated effects modeling technique developed by Chudik et al. (2016) and refined by Ditzen (2018). This approach accounts for unobservable common factors that could affect the sectors.

In our case, the lagged dependent variable is not strictly exogenous, thus Pesaran's (2006) common correlated effects (CCE) approach to estimate panel models in the presence of transverse dependence becomes inconsistent. Chudik et al. (2016) show that the estimator is more consistent if a delay is added to the cross-section means used in the estimation. Thus, Eq. (2) is rewritten as

$$LVA_{it} = \alpha_0 + \sum_{j=1}^{P} \beta_{it} LVA_{i,t-j} + \sum_{j=0}^{P} \alpha_{it} X_{t-j} + \sum_{j=0}^{3} \phi_{it} \overline{Z}_{t-j} + \varepsilon_{it}, \qquad (3)$$

Table 1 Slope homogeneity test (Pesaran and Yamagata, 2008)

Slope homogeneity tests	Δ statistic	*p* value
$\tilde{\Delta}$ test	19.475***	0.000
$\tilde{\Delta}_{adj}$ test	21.888***	0.000

The null hypothesis for the slope heterogeneity test is that slope coefficients are homogenous

*** denotes significant at 1% level

Table 2 Pesaran (2015) test for weak cross-sectional dependence

Variables (in log)	CD statistic	*P* value
Value added (LVA)	46.716***	0.000
Gross fixed capital formation per capita (LGFCF)	18.012***	0.000
ICT diffusion index (LIDI)	45.848***	0.000
Trade openness (LTO)	15.565***	0.000

The CD statistic is normally distributed under the null hypothesis of no cross-sectional dependence

*** denotes significant at 1% level

with $\overline{Z}_t = \left(\Delta \overline{LVA_t}, \overline{X}'_t \right)'$ and $X_{it} = \left(LGFCF_{it}, LIDI_{it}, LTO_{it} \right)'$.

4 Results and discussion

Table 1 presents the results for the Pesaran and Yamagata (2008) test. The null hypothesis of slope homogeneity is rejected (*p* value = 0.000). Thus, we need to consider the presence of heterogeneity in the panel data and can deduce that the model coefficients are heterogeneous and that slopes vary from country to country. This requires use of heterogeneous panel techniques.

The results of Pesaran's (2015) cross-dependence test (Table 2) confirm the existence of cross-sectional dependence for all the variables in the panel data.

This indicates the existence of a dependency factor among sectors which is evidence of the existence of a mechanism for transmitting shocks between sectors. Hence, we need to perform a second-generation unit root test.

Table 3 reports the results of the CIPS and CADF tests in levels and first differences. The assumptions of these tests require that if two or more non-stationary time series are integrated in a particular order, it is possible to estimate the cointegration regression. Therefore, the order of integration of the variables must first be determined. The results of the CIPS and CADF tests suggested that with the exception of LGFCF which is stationary in level, I(0) all the other variables are stationary in first differences I(1). We investigate the possibility of cointegration among these variables using Westerlund's (2007) and Pedroni's (2004) panel

Table 3 Results of panel unit root

Variables (in log)	Level		First-difference		Order
	Without trend	With trend	Without trend	With trend	
Cross-sectionally augmented IPS (CIPS)					
LVA	− 1.755	− 2.261	− 4.469***	− 4.487***	I(1)
LGFCF	− 2.727***	− 2.401	− 4.106***	− 4.139***	I(0)
LIDI	− 1.971	− 2.899**	− 5.242***	− 5.203***	I(1)
LTO	− 2.296**	− 2.494	− 4.823 ***	− 4.888***	I(1)
Cross-sectionally augmented Dicky–Fuller (CADF)					
LVA	− 1.733	− 1.799	− 2.171*	− 2.148	I(1)
LGFCF	− 2.162*	− 2.270	− 2.374**	− 2.313	I(0)
LIDI	− 1.267	− 2.557	− 2.879***	− 2.873**	I(1)
LTO	− 1.525	− 1.728	− 2.362**	− 2.450	I(1)

The panel unit root test was performed under the null hypothesis that the variables are homogeneous and non-stationary

***, **, and * denote statistical significance level at 1%, 5%, and 10%, respectively

Table 4 Westerlund (2007) panel cointegration tests

Statistic	Value	Z-value	P value
Gt	− 3.768***	7.521	0.000
Ga	− 11.554**	2.242	0.013
Pt	− 14.446***	7.263	0.000
Pa	− 11.051***	4.018	0.000

The Gt and Ga statistics test cointegration for each cross-section, and Pt and Pa test cointegration in the panel under the null hypothesis of no cointegration

*** and ** denote statistical significance level at 1% and 5%, respectively

cointegration tests which allow us to determine the existence in the long run of a correlation between several time series.

Table 4 presents the results for all the variables of the Westerlund (2007) cointegration test using data for 14 sectors. This method has the advantage of testing cointegration in the presence of heterogeneous slope coefficients and dependence among individual data in the panel. The null hypothesis is that there is no long-term cointegration among the variables; the alternative hypothesis assumes the opposite.

The results of the Westerlund (2007) test reject the hypothesis of non-cointegration at the panel rather than at the individual level. The results of the Pedroni (2004) test (Table 5) indicate that the null hypothesis of no cointegration is

Table 5 Pedroni (2004) panel cointegration test

Tests	Within-dimension		Between-dimension	
	Statistic	P values	Statistic	P value
ν-statistic	− 0.3352	0.368		
ρ-statistic	− 3.716***	0.000	− 2.383***	0.008
PP-statistic	− 8.202***	0.000	− 9.006***	0.000
ADF-statistic	− 7.973***	0.000	− 8.516***	0.000

All test statistics are normally distributed under a null hypothesis of no cointegration

*** denotes significant at 1% level

Table 6 CS-ARDL panel data estimation results

	Model 1 (All sectors)		Model 2 (Less ICT-intensive sectors)	
	Coefficient	P value	Coefficient	P value
Short-run results				
ECT	− 0.768*** (0.1084)	0.000	− 0.696*** (0.1451)	0.000
LGFCF	0.110** (0.0430)	0.011	0.135* (0.0744)	0.069
ΔLIDI	0.130** (0.0538)	0.016	0.082** (0.0326)	0.012
ΔLTO	0.148*** (0.0486)	0.002	0.167* (0.0950)	0.079
Long-run results				
LGFCF	0.063*** (0.0216)	0.004	0.068** (0.0322)	0.034
LIDI	0.079** (0.0312)	0.011	0.049*** (0.0184)	0.008
LTO	0.100*** (0.0332)	0.003	0.085 (0.0515)	0.100
CD statistic	− 0.51	0.608	− 0.54	0.586
Root MSE	0.05		0.06	

The CD statistic test is standard normally distributed under the null of hypothesis of weak cross-sectional dependence. Coefficients are reported with standard errors in brackets

***, **, and * denote statistical significance level at 1%, 5%, and 10%, respectively

rejected for six of the seven statistics. We therefore need to estimate the long-term equilibrium relationships among the variables.

The CS-ARDL model results for the short-term (top rows) and long-term (bottom rows) relationship are presented in Table 6. Note that the short-term results of the CS-ARDL model are similar in magnitude and sign to the long-term results.

We note also that the CD test (p value 0.586) does not reject the null hypothesis of weak cross-section dependence, suggesting that the estimation results are not biased by the presence of cross-section dependence.

The results show that as expected, the coefficient of the error correction term (ECT) is negative and significant (− 0.768, $p = 0.000$). Thus, the ECT provides no evidence rejecting cointegration. Similarly, the long-run results based on the CS-ARDL estimator suggest that VA is positively and significantly related to GFCF, trade openness and ICT. A 1% increase in LGFCF, LTO and LIDI, increases LVA by 0.11%, 0.15% and 0.13%, respectively.

LIDI is significant at the 5% level, indicating that availability and diffusion of ICTs can enhance VA growth through multiple transmission channels.

First, firms use the outputs of the ICT sector either as capital goods (embodied technical progress) or as intermediate consumption goods which is supposed to foster growth of VA. Households also demand ICT products as final consumption goods which stimulates growth. The main mechanism assumed here is related to the existence of a Keynesian ICT investment multiplier which is larger than the non-ICT investment multiplier. Thus, investment regains fundamental importance not directly as a factor of growth but indirectly as a vector of technical progress.

Second, the downward slide in ICT prices has a deflator effect on the rest of the economy. For example, the continuing sharp reductions in hardware and software prices, have led firms to intensify their ICT investments. Productivity gains in the ICT sector act as a technology deflator on the rest of the economy, controlling inflation and/or increasing real income and growth.

Third, the relative increase in the share of capital over labor in the use of inputs when ICT is considered as a biased technology. In this case, capital substitutes for labor, and skilled labor displaces unskilled labor in the investment process. This generates an increase in capital intensity and productivity and allows for changes in the organization of production, markets and firms, a rethinking of business practices, simplification of the supply chain and a reduced transaction costs.

Fourth, by increasing the informational content of goods and services, ICTs increase the quality and differentiation of products and services. These benefits improve the utility of consumers without changing the price or quantity of the products that incorporate ICTs.

Fifth, the externalities and spillover effects among sectors associated with ICTs are widely diffused throughout the economy and increase production efficiency and rates of technical progress.

Tables 7 and 8 show that overall, our sectoral study reveals important heterogeneity in the impacts on economic growth across sectors of the variables studied. Heterogeneity across sectors has been shown to be an important characteristic of the Tunisian economy.

While trade openness appears to have a positive and statistically significant effect on economic growth over the long term, the results at sectoral level are mixed with seemingly only a few sectors benefitting. However, this weak impact

Table 7 Results of long-term estimates at the sector level

Sector	LGFCF	LIDI	LTO
S1: Agriculture, forestry and fishing	0.003 (0.0226)	0.030 (0.0267)	0.254* (0.1540)
S2: Mining and quarrying	0.106** (0.0487)	− 0.100 (0.0856)	0.232*** (0.0837)
S3: Manufacturing	0.021** (0.0089)	0.092 (0.0594)	0.092* (0.0531)
S4: Electricity, gas, steam and air conditioning supply	0.131*** (0.0235)	0.189* (0.1006)	− 0.055 (0.2646)
S5: Water supply; sewerage, waste management and remediation activities	0.220*** (0.0411)	− 0.060 (0.0761)	− 0.021 (0.0449)
S6: Construction	0.248** (0.1209)	− 0.062 (0.2856)	0.077 (0.1628)
S7: Wholesale and retail trade	0.603*** (0.1710)	0.492*** (0.1537)	− 0.168*** (0.0421)
S8: Transportation and storage	0.160*** (0.0422)	0.004 (0.1103)	− 0.090 (0.1185)
S9: Accommodation and food service activities	0.270*** (0.0982)	0.144* (0.0806)	− 0.036 (0.0423)
S10: Information and communication	0.332*** (0.1098)	1.005*** (0.1341)	0.345*** (0.0831)
S11: Financial and insurance activities	0.517* (0.2898)	0.314* (0.1697)	− 0.028 (0.0301)
S12: Real estate activities	− 0.027 (0.0873)	0.002 (0.0435)	− 0.009 (0.0526)
S13: Professional, scientific and technical activities	0.102* (0.0594)	0.061* (0.0329)	0.368 (0.2262)
S14: Public administration	0.008 (0.0659)	0.092* (0.0506)	− 0.040 (0.0726)

Coefficients are reported with standard errors in brackets

***, **, and * denote statistical significance level at 1%, 5%, and 10%, respectively

can be reversed by structural reforms aimed at improving access to investment, human capital, innovation capabilities, and competitiveness and diversifying the economy.

In terms of the effect of the diffusion of ICTs and digitalization of the economy on sectoral performance, it should be noted that all sectors of the economy including traditional sectors which would be less likely to be affected, will be impacted by the changes promoted by the introduction of digital technologies. The digital transformation will affect all sectors to varying degrees. Some such as tourism and trade are heavily influenced by digitization. Traditional players in these sectors have had to redesign their business models: for example, tour operators have been forced to reconsider the scope and operation of their physical agency networks, while airlines have increased direct distribution which relies on use of the internet. On the other hand, some sectors are only beginning this

Table 8 Long-run elasticity of value added with regard to ICT: industry level

Sector	ICT diffusion index (LIDI)		
	1995–2018	1995–2009	2004–2018
S1: Agriculture, forestry and fishing	0.030 (0.0267)	0.051 (0.0910)	0.040 (0.0265)
S2: Mining and quarrying	− 0.100 (0.0856)	− 0.184 (0.2439)	− 0.450 (0.5712)
S3: Manufacturing	0.092 (0.0594)	0.053 (0.0267)	0.107 (0.0756)
S4: Electricity, gas, steam and air conditioning supply	0.189* (0.1006)	0.915*** (0.1809)	0.366*** (0.1158)
S5: Water supply; sewerage, waste management and remediation activities	− 0.060 (0.0761)	0.131 (0.1928)	− 0.024 (0.0809)
S6: Construction	− 0.062 (0.2856)	− 0.331 (0.2526)	0.016 (0.4045)
S7: Wholesale and retail trade	0.492*** (0.1537)	− 0.459 (0.3592)	0.847*** (0.1446)
S8: Transportation and storage	0.004 (0.1103)	0.249** (0.1078)	− 0.059 (0.1787)
S9: Accommodation and food service activities	0.144* (0.0806)	0.229* (0.1192)	0.031 (0.0627)
S10: Information and communication	1.005*** (0.1341)	1.401** (0.6334)	0.926*** (0.3213)
S11: Financial and insurance activities	0.314* (0.1697)	0.078 (0.1415)	0.242*** (0.0677)
S12: Real estate activities	0.002 (0.0435)	− 0.117 (0.1811)	0.305 (0.2214)
S13: Professional, scientific and technical activities	0.061* (0.0329)	0.059** (0.0267)	− 0.073 (0.0465)
S14: Public administration	0.092* (0.0506)	0.141** (0.0668)	0.097 (0.0690)

***, **, and * denote statistical significance level at 1%, 5%, and 10%, respectively

transformation. For example, only the most pioneering construction sector firms are testing and adopting digital construction technologies.

Some of the leading economic sectors are heavily involved in the digital transformation. Financial and insurance activities, professional, scientific and technical activities, transportation and storage and public administration are among the sectors most affected by the digital transformation in Tunisia. While some sectors are benefiting immediately, others face several obstacles in the move to this new paradigm. This applies particularly to agriculture, construction and manufacturing. Although the agriculture sector could benefit greatly from digitization, it is slow to adopt new technologies. In most cases, in Tunisia agriculture continues to use traditional practices. The construction sector also is lagging behind some other sectors. This delay in digitization of the construction sector is resulting in both lower productivity and profitability, and is likely to fail to meet Tunisia's future construction

needs to satisfy demand from an increased urban population. Tunisia suffers from water shortages and the deployment of water saving or water use efficiency technologies is essential. Some incentives have been provided in this area but much more needs to be done to invest in Water 4.0.

4.1 Robustness

To analyze model uncertainty and test whether the estimated effects are sensitive to changes in the model specification, we check the robustness of the CS-ARDL model results (Table 6). First, we estimate model 1 which includes all sectors. Second, we estimate model 2 which excludes the most ICT-intensive sectors and compare the changes in the coefficient and statistical significance of each variable in model 2. Third, we employ the Dumitrescu and Hurlin (2012) causality test to check for a causal relationship among the variables.

The results of the Dumitrescu and Hurlin (2012) panel Granger causality test for the CS-ARDL model are presented in Table 9. We observe four bidirectional causal relationships between VA↔GFCF, VA↔ICT Index, VA↔Trade, and ICT Index↔Trade, and evidence of two unidirectional causal relationships: GFCF→Trade, and ICT Index→GFCF.

The estimation results for models 1 and 2 and the results of the causality test are consistent, suggesting that the models are robust and do not suffer from mis-specification.

5 Conclusion and policy implications

We set out to investigate the dynamic relationship between ICT diffusion, trade openness and economic growth drawing on the work by Huchet-Bourdon et al. (2018), Carnevali et al. (2020), Toader et al. (2018), Zaman et al. (2021), Mickoleit et al. (2009), Antonelli (2017), Fukuda (2020), Toader et al. (2018), Frank et al. (2019); Park (2018), Vu et al. (2020), Taalbi (2019), Czernich et al. (2011), and Fernandez-Portillo et al. (2020) who consider trade openness and ICT diffusion relevant

Table 9 Dumitrescu and Hurlin (2012) Granger non-causality tests

	Value added	GFCF	ICT Index	Trade openness
Value added		18.2796***	3.8614***	4.2455***
		13.2635	7.5707	8.5868
GFCF	2.8524***		1.5188	1.6522*
	4.9009		1.3725	1.7256
ICT Index	1.7841**	63.8949***		6.9847***
	2.0745	62.5336		15.8341
Trade openness	3.5396***	1.5751	2.0608***	
	6.7191	1.5217	2.8066	

The W-statistics marked with (***) are statistically significant at 1% level. Z-statistics are shown in parentheses

factors to foster economic activity, create jobs and improve the quality of products and services. To capture the economic importance of ICT, we considered the role of ICT sector outputs in the VA of each sector. We obtained three main findings which have some policy implications.

First, we found a positive impact of ICTs on economic growth. In addition, the results show a bidirectional causal relationship between ICT and VA which suggests that the Tunisian economy should focus more on manufacturing of ICT products to sustain economic growth. Tunisia should strengthen its digital infrastructure and deploy new technologies. Tunisian enterprises should prioritize implementation of new organizational practices to enable adoption of new digital technologies. The workforce must be trained in the digital skills that will be required for tomorrow's jobs. Bridging the digital divide should be a priority; digital inclusion drives economic development and growth.

Second, value added is positively and significantly related to trade openness in the long run. The sectoral level results are mixed with only a few sectors appearing to benefit. However, this weak impact could be reversed by continuing structural reforms to improve access to investment, human capital, innovation capacity, competitiveness and economic diversification. In addition to contributing directly to output growth, ICT generates natural advantages and openness effects (ICT has a causal effect on trade openness). In the case of significant effects, this would translate into accelerated multifactor productivity growth.

Third, the results suggest that VA is related positively to GFCF. ICT has a positive impact on investment. ICT allows the creation of new capital goods, significantly improved existing products and development of new services.

With the exception of a few sectors, investment in ICT does not have a significant effect on productivity at sectoral level. This can be explained by lack of investment and organizational change required to adopt new technologies in some sectors. In addition, on its own technology cannot solve development problems; technology only provides opportunities.

In summary, Tunisia has taken some important steps towards becoming a knowledge economy but needs to overcome numerous economic, social, political, cultural and education obstacles. To benefit from the opportunities enabled by an information economy, Tunisia must prioritize investment in R&D, and science and technology and implement projects to encourage innovation and spillover effects among economic sectors. To reap the benefits from trade openness and increase international trade involving domestic enterprises, and to overcome traditional institutional and legal barriers will require adjustments to legal framework to enable easy and secure information exchange.

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