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**The Role of ICT and Financial Development on CO2 Emissions and Economic Growth**

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# The Role of ICT and Financial Development on CO2 Emissions and Economic Growth

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**Abstract**

This study explores the role of the information and communication Technology (ICT) and financial development (FD) on both carbon emissions and economic growth for the G7 countries for the period 1990-2014. Using PMG, we found that ICT has a long run positive effect on emissions, while FD is a weak determinant. The interactive term between the ICT and FD produces negative coefficients. Also, both variables are found to impact negatively on economic growth. However, their interactions show they have mixed effects on economic growth (i.e., positive in the short-run and negative in the long-run). Policy implications were designed based on these results.

*Keywords*: ICT; Financial development; Carbon emissions; Economic growth and G7 countries

*JEL Classification*: E23; F21; F30; O16

## 1.-Introduction

Among the distinctive features of globalization is the consequent surge in Information and Communication Technology (ICT) and Financial Development (FD) (Chavanne et al., 2005; Danish et al., 2018). The growing literature has examined the effect of ICT development on various variables using different perspectives. For instance, ICT has been linked to economic prosperity (Qureshi, 2013a and Levendis and Lee, 2013, Asongu 2017); living standards and welfare (Chavula, 2013; Qureshi 2013b), sustainable development (Byrne, 2011); banking (Kamel, 2005; Andrianaivo and Kpodar 2011, 2012, Watson et al. 2012); carbon emissions (Batool et al., 2019; Tsaurai and Chimbo, 2019; Khan et al., 2019; Sinha, 2018 and Asongu, 2018, Ozcan and Apergis, 2017; Zhang and Liu, 2015;to mention a few), and the economic growth process (Penard et al. 2012, Asongu 2013, Murphy and Carmody 2015, Tchamyou 2017 Amavilah et al., 2017). In a general conclusion from the above studies, one can observe ICT as a double sword-edge. On the positive side, ICT has been argued to fuel industrialization, which in turn drives economic growth. The negative side ICT may have harm to the environment due to increase in the industrialization. Being explicit, industrialization is based on the increased energy consumption which leads to poor environmental conditions and harmful impact on the man-kind.

FD, on the other hand, is considered an important ingredient of economic growth. The narrative is that the financial sector acts as the link between the surplus and deficit sectors of the economy together. Thus, FD enhances the mobilisation, utilization, monitoring of funds (Raheem and Oyinlola, 2013). It has also been argued that ICT could further enhance the development of the financial sector. For instance, internet usage helps to boost investment activities, reduces cost of bank loans and has the tendency to increase trading activities, effective allocation and monitoring of resources.

This is just as financial sector encourages firms and industries to acquire modern technologies that are considered environment friendly (Andrianaivo and Kpodar, 2011; 2012; Latif et al. 2017; Nasreen et al. 2017). For example, Datta and Agarwal (2004) found that investments in ICT could reduce costs because better communication systems lower transaction costs. Therefore, ICT can improve access to credit and deposit facilities, allow more efficient allocation of credit, facilitate financial transfers, and boost financial inclusion.

Batool et al. (2019) explored the connection between ICT, economic growth, energy consumption, and carbon emissions in South Korean during 1973-2016. The empirical results show that ICT helps to reduce environmental degradation in a medium and long runs. Khan et al. (2018) show that there is a moderating effect of ICT and FD on the level of emissions, while the interaction between ICT and GDP contributed positively to mitigate emissions. Tsaurai and Chimbo (2019) explore the impact of ICT on carbon emissions in emerging markets from 1994 to 2014. The study reveals that FD and economic growth are channels through which ICT influences carbon emissions. In the BRICS context, some studies have found that internet usage, a proxy for ICT, enhances carbon emission. This thus negatively impacts on environmental quality (Balsalobre et al., 2019 and Haseen et al. 2019). Similar results were obtained by studies that focus on the Asian region (see for instance Lee and Brahmasrene, 2014 and u, 2018). Asongu (2018) find that ICT can be employed to dampen the potentially negative effect of globalisation on environmental degradation. Ozcan and Apergis (2017) found that internet access, a proxy of ICT, contributed to reduce air pollution, for a panel of 20 emerging economies during the period 1990 to 2015. Salahuddin et al. (2016) found that a one percent increase in ICT usage will cause 0.16% increase in CO2 emission. In an interesting twist, Higon et al. (2017) estimated a nonlinear relationship for both developed and developing countries and found an inverted U-shaped relationship.

The foregoing suggests that the exact effect of ICT is heterogeneous to the variables under consideration. The net effect of ICT is difficult to ascertain. While ICT is seen as a driver of economic growth, poor environmental conditions could also arise from the usage and implantation of ICT and its other related products. Plainly, ICT has differential impacts on economic growth and carbon emissions. This study is pitched under two major strands of the literature: ICT-economic growth nexus and ICT-carbon emission nexus. In this study, we hypothesize that FD should be considered as an intervening variable in these nexuses. This is due to the fact that the FD could further enhance the economic growth strides of ICT and can also mitigate against the detrimental effects of ICT on the environment. As such, we want to examine the extent to which FD magnifies or dampens the above nexuses. We test this hypothesis by interacting ICT with FD in the two models (i.e. $CO_2$ emissions and economic growth).

This study contributes to the literature in a number of ways: (i) As far as we are aware, this is the first study to examine the role of ICT and FD on both economic growth and carbon emissions. Previous studies have limited their empirical findings to either economic growth or emission model. This exercise becomes important because of the differing effect of ICT on economic growth and emission and we are addressing both issues with same data; (ii) We limit our analysis to the G7 countries, because they are among the top carbon emitters and also brand developed financial systems; (iii) We explore the heterogeneous and cross-section dependence features of panel estimation techniques such as Pooled Mean Group (PMG), Mean Group (MG) and Dynamic Fixed Effects (DFE) while most of the previous studies have failed to do so.

Our overall results suggested that ICT enhances carbon emissions; however the interactive terms of ICT and FD help to upturn this detrimental consequence on emission. Though, this result is sensitive to the measures of ICT. It is also found that ICT and FD individually had a weak effect on growth, and in most cases defy theoretical expectations. Mixed results were obtained when the variables of interest are interacted.

The rest of the paper is structured as follows. Data and methodology are exposed in Section 2. Section 3 presents empirical results and discussions. Finally, Section 4 concludes and proposes policy recommendations.

## 2.-Model specification, Data and Methodology

This section is divided into two sub-sections. In the first sub-section, we discuss the model specifications and data related issues. Next to this, we give a brief highlight on the methodology.

### 2.1 Model specification and data issues

This study considers the intervening role of FD on the effect of ICT on two distinct models ($CO_2$ and economic growth). This is achieved using the specifications below:

$$CO_{2it} = \propto + \beta ICT_{it} + \gamma FD_{it} + \delta X'_{it} + \theta ICT * FD_{it} + \mu GDP_{it} + \varepsilon_{it} \quad (1)$$

$$GDP_{it} = \propto + \beta ICT_{it} + \gamma FD_{it} + \delta X'_{it} + \theta ICT * FD_{it} + \mu CO_{2it} + \varepsilon_{it} \quad (2)$$

where $CO_2$ is the carbon emissions per 1000 metric tons. GDP is the growth rate of the Gross Domestic Product. ICT implies development of the ICT sector. An overview of the literature suggests that there are three ways to measure ICT. The first way is tagged ICT readiness, which dwells on the level of ICT access and infrastructure. The second one is to focus on the ICT use, which measures the intensity of the use of ICT. The third way is to use a measure of ICT impact, which evaluates the resultant effect of the effective and efficient use of ICT (ITU, 2009 and 2010; OECD, 2006; UNCTAD, 2008). Due to data limitation, the proxies for ICT are limited to ICT readiness and use phases. Principally, we proxy ICT readiness using fixed telephone lines per 100 people and mobile cellular telephone subscriptions per 100 people. As regards ICT intensity, the most commonly used proxies are internet users per 100 people, cellular users per 100 people and fixed broadband Internet subscribers per 100 people. However, data unavailability constrained us to use internet users per 100 people. FD is measured as the credit provided by the private sector. X' is a vector of the control variables which includes urban population (measured as a proportion of total population) and trade openness (the summation of import and export measured as a proportion of GDP).

The scope of this study is limited to the G7 countries (United Kingdom, United States of America, Canada, Italy, Japan, Germany and France.) Annual dataset that covers the period 1990 to 2014 is used. The main data sources are the World Development Indicators (WDI).

## 2.2 Methodology

The starting point of our analysis is to examine the order of integration of all the series in the model. It is generally accepted that panel unit root tests are more powerful as compared to the time series tests (Maddala and Wu, 1999; Breitung, 2000; Levin et al., 2002; Im et al., 2003). The tests considered are Im, Pesaran and Shin (2003), (hereafter IPS) and Maddala and Wu (1999). Furtherance to this, we follow the procedure outlined by Pesaran (2004) to carry out cross-sectional dependence (CD). Next, the long-run relationship among the series in the model is examined using panel cointegration formulated by Westerlund (2007), which is based on structural rather than residual dynamics and allow for a large degree of heterogeneity. The novelty of Westerlund (2007) over previous tests such as Pedroni (2004) is that the former has no restriction for common factors in a bid to preserve the test power. The major distinction between homogenous models and that of heterogenous models is that in the case of the former, ($\propto_i = \propto_1$, $\beta_i = \beta_1$, $\delta_i = \delta_1$, $\theta_i = \theta_1$), while in the case of the latter, ($\propto_i \neq \propto_1$, $\beta_i \neq \beta_1$, $\delta_i \neq \delta_1$, $\theta_i \neq \theta_1$). Static models such as Pooled OLS, instrumental variables, GMM can be used to estimate the former. In the latter, Mean Group (MG) estimator (Pesaran and Smith, 1995) or its variants such as Augmented Mean Group (AMG) estimators, Pooled Mean Group (PMG) or Dynamic Fixed Effects (DFE) (Eberhardt and Bond, 2009; Eberhardt and Teal, 2011). The use of MG involves two steps. In the first step, the model is estimated using time series OLS on each panel separately including an intercept to capture fixed effects and (optionally) a linear trend to capture time-variant unobservables. The second stage involves averaging the estimated individual-specific slopes with or without weights. In the dynamic case, when the coefficients are heterogeneous across groups, the MG estimators are consistent for large T and N (Pesaran and Smith, 1995). Hausmann's test is used to determine the best estimators, among the variants of MG that suits the models.

**2.3 Panel Cointegration Test**

The cointehration test employed in this study is the Westerlund (2007) due to its high power as compared to other residual based test such as the Pedroni (2004). The estimation procedure of the test is conducted in four panels and the null hypothesis of no long run relationship is conducted by testing whether the error correction term in a conditional error correction model is equal to zero. Westerlund (2007) considers the following error correction model where all variables in levels are assumed to be integrated of order 1;

$$\Delta Y_{it} = \delta_i^{'} d_t + \alpha_i (Y_{it-1} - \beta_i^{'} x_{it-1}) + \sum_{j=1}^{pi} \alpha_{ij} \Delta Y_{it-j} + \sum_{j=0}^{pi} Y_{ij} \Delta x_{it-j} + e_{it} \quad (3)$$

where $d_t$ = (1, t)′ holds the deterministic components, $\delta_i^{'}$ = ($\delta_{1i}$,$\delta_{2i}$)′ are the associated vector of parameters. In order to allow for the estimation of the error correction parameter $\alpha_i$ by least squares;

$$\Delta Y_{it} = \delta_i^{'} d_t + \alpha_i Y_{it-1} - \lambda_i^{'} x_{it-1} + \sum_{j=1}^{pi} \alpha_{ij} \Delta Y_{it-j} + \sum_{j=0}^{pi} Y_{ij} \Delta x_{it-j} + e_{it} \quad (4)$$

Here the parameter $\alpha_i$ provides the estimate for the speed of adjustment towards the long run equilibrium. Next, it is possible to construct a valid test of $H_o$ versus $H_a$ that is asymptotically similar and whose distribution is free of nuisance parameters. Westerlund (2007) proposes four tests based on the least squares estimates of $\alpha_i$ and its t-ratio for each individual i. The first two are called 'group mean' and given as:

$$G_t = \frac{1}{N}\sum_{i=1}^{m} \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \text{ and } G_\alpha = \frac{1}{N}\sum_{i=1}^{m} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)}$$

where SE ($\hat{\alpha}_i$) is the standard error of $\hat{\alpha}_i$. $G_t$ and $G_\alpha$ test the null of $H_o$: $\alpha_i$= 0 for all i versus the alternative of $H_a$: $\alpha_i$< 0 for at least one i. In other words, the $G_t$ and $G_\alpha$ test the null hypothesis of no cointegration for all cross-sectional units against the alternative that there is cointegration of at least one cross-sectional unit. The rejection of the null should therefore be taken as evidence of cointegration of at least one of the cross-sectional units. The other two tests are called 'panel test' and given as follows:$P_t = \frac{\hat{\alpha}}{SE(\hat{\alpha})}$ and $P_\alpha = T\hat{\alpha}$

The $P_t$ and $P_\alpha$ test $H_o$: $\alpha_i$= 0 for all i versus the alternative of $H_a$: $\alpha_i$< 0 for all i. the rejection of the null hypothesis suggests that there is evidence of long run relationship in the panel as a whole. It should be noted that small sample size might be sensitive to the choice of lag and lead lengths, thus implying that the existence of cross sectional dependence over the units might cause the group mean and panel statistics to be invalid (Westerlund, 2007). Bootstrapping can be obtained through robust critical values, which will help avoid over-parameterization.

## 3.-Empirical Results

### 3.1.-Preliminary Statistics

As a starting point, we presented the descriptive statistics in Table 1. It can be deduced that internet usage, number of fixed telephone lines and mobile cellular have mean values of 2.6, 3.9 and 16.9, respectively. The average size of the financial sector is calculated to be 4.5%. The average growth rate of G7 countries is estimated to be 10.43. Based on standard deviation, the most volatile series is trade openness.

**Insert Table 1 about here**

Table 2 presents the first-generation unit root test of Maddala and Wu (1999) and the second-generation test of Pesaran (2007) IPS (Z[t-bar]). The first-generation test assumes cross-sectional independence and they exhibit low power if estimated with heterogeneous panel data with cross-sectional dependence. To account for cross-sectional dependence, the series were examined using the IPS unit root test. All series were tested based on two specifications; “with intercept” and “with intercept and trend”. In addition, the maximum lag for each series was set at 2 based on SIC. The results show that all the measures of ICT and urbanization are stationary, while other variables are seen to be non-stationary.

**Insert Table 2 about here**

Table 3 presents the information of cross-sectional dependence. Overall, from Table 3, it can be established that the null hypothesis of the test can be accepted for telephone lines, and GDP.

**Insert Table 3 about here**

Table 4 presents the results of cointegration which are obtained using Westerlund (2007) cointegration test. It is evident from Table 4 that series are cointegrated providing the indication that our series have long run relationship.

**Insert Table 4 about here**

## 4.-Main Result Presentation

As stated in the preceding section, the three variants of the PMG estimator used are PMG, MG and DFE. To draw conclusions however, we will rely on the results obtained from the PMG estimates[1]. Results of the baseline model are presented in Table 5. Summarizing the findings from Table 5, we confirm a positive connection between internet usage and economic growth, a finding similar to previous studies' results (Roller and Waverman 2001; Inklaar et al. 2005; Koutroumpis 2009). We also find that internet usage presents a direct connection with carbon emissions (Salahuddin and Alam, 2015).  Next to this, we estimated an extended model to account for the role on interaction between variables of interest whose results are presented in Tables 6-8.

Table 6 presents the results of internet usage. Starting with the $CO_2$ emission equation, it could be deduced that in the long run, ICT is a positive and significant determinant. The coefficient ranges between 0.105 – 0.631. These results suggest that a 1% increase in carbon emission would lead about 343 basis point increase in internet usage (based on PMG which is the preferred results). This result is quite similar to an earlier literature such as Lee and Brahmasrene (2014), Zhang and Liu (2015) and Salahuddin et al. (2016) to name a few. However, in the short run, ICT seems to have a very weak effect on the carbon emissions. The short-run result is similar to the findings of Asongu et al. (2017). Financial development (FD) has a positive, but weak, effect on carbon emissions. This is in line with the conclusion of Ozturk and Acaravci (2013). The

[1] Haussmann's test result favours PMG.

interactive term between FD and ICT yields positive and significant coefficient. Thus, this suggests that the insignificant effect of FD can be upturned with the help of the ICT. This result is quite intuitive as the financial sector heavily relies on the ICT sector for effective service delivery.

We now turn to the economic growth model. It is surprising to find that FD serves as growth drag, although estimated coefficients confirm a weak statistical significance. This, thus, contradicts the exiting literature which documents that FD has a positive effect on economic growth (See Raheem and Oyinlola, 2013).

Trade and urbanization are explanatory variables found to improve the growth trajectories of the countries under investigation. The developed countries could purse economic growth agenda through making concerting efforts in formulating policies that would seek to improve these variables. These results, to a large extent, follow economic intuition and apriori expectations. The interactive term between ICT and FD yields negative and significant coefficients. This implies that the negative effect of FD is further amplified by the weak coefficient of ICT. It is also worthy to note that the bi-directional relationship between carbon emission and growth was confirmed in this study. Hence, increase in emission would mean that there is relative increase in the manufacturing sector, which further translates to increase in the economic growth.

The estimated error correction term (ECT) fulfils the three statistical requirements in terms of sign (being negative), size (less than one) and statistical significance. These results are robust to changes in the measure of ICT development. These results are robust to alternative measures of ICT.

**Insert Table 5 about here**

**Insert Figure 1 about here**

**Insert Table 6 about here**

**Insert Table 7 about here**

**Insert Table 8 about here**

**Insert Figure 2 about here**

## 5. Conclusion

The importance and attention that information communication and technology has been enjoying in the past few decades served as motivation to this study. While a section of the literature has argued that there is enormous benefit of ICT, another strand has documented the negative effect of ICT development. However, the general notion in the literature is that the eventual benefits of ICT depend on the variables being considered. Thus, the effect of ICT is considered for both $CO_2$ emissions and economic growth. The study further argues for the introduction of an intervening variable, in this case, financial development, to enhance the relationship that might exist between ICT and emissions, on the one hand and ICT and economic growth, on the other hand.

Based on data for G7 countries, we establish that ICT has a long run positive effect on $CO_2$ emissions, while financial development seems to be a weak determinant of the carbon emissions. However, the interactive term between ICT measures and FD produces positive coefficients. This implies that ICT magnifies the effect of FD on emissions. On the flip side, ICT and FD have no meaningful effects on economic growth. In fact, these variables could be considered to be growth drags. The interactive term between these variables show they have mixed effects on growth i.e., positive in the short-run and negative in the long-run. A positive bi-directional relationship was confirmed for $CO_2$ emissions and economic growth.

Despite the innocent benefits due to ICT, its detrimental effect on environment and weak impact on the economy cannot be waived aside. In terms of policy implications, caution must be exercised when clamouring for the improvement of ICT, as its benefit is considered vague. In other words, policymakers should create awareness regarding the benefit and cost of ICT. When making projections for economic growth, special emphasis should be accorded to the emissions, as there is a two-way causality between them. In other words, policies that would enhance economic growth without necessarily being accompanied by increase in emissions should be encouraged. In a bid to reduce emissions, the major problems such as enforcement, regulations and environmental management should be given upmost importance. These are social and economic problems that cannot be disentangled from each other. As a follow up to the above, policymakers should encourage policies geared towards ensuring environmental sustainability, as the present growth process is detrimental to environmental quality. Along this line, cleaner and renewable forms of energy could be a plausible option to follow.

**TABLES:**

**Table 1: Descriptive Statistics**

| | Mean | Std Dev | Min | Max |
|---|---|---|---|---|
| INT | 2.613 | 2.226 | -4.043 | 4.517 |
| TEL | 3.960 | 0.157 | 3.517 | 4.222 |
| CELL | 16.943 | 1.785 | 12.491 | 19.689 |
| GDP | 10.437 | 0.131 | 10.184 | 10.746 |
| $CO_2$ | 6.739 | 0.864 | 5.789 | 8.718 |
| FD | 4.599 | 0.385 | 3.789 | 5.298 |
| URB | 17.926 | 0.674 | 16.874 | 19.275 |
| TRADE | 47.234 | 17.809 | 15.923 | 85.889 |

Source: Authors' computation
Note: INT, TEL and CELL represents internet usage, number of telephone lines and mobile cellular, respectively. CO2 implies carbon emissions, FD is financial development URB is urban population, while TRADE is trade openness.

**Table 2: Test for unit roots**

| | Maddala and Wu (1999) | | | IPS | | |
|---|---|---|---|---|---|---|
| Lags | 0 | 1 | 2 | 0 | 1 | 2 |
| With Trend | | | | | | |
| INT | 307.537*** | 68.159*** | 84.344 | -2.855*** | -3.888*** | -2.273**** |
| FD | 3.853 | 6.745 | 5.089 | -0.954 | 0.710 | -0.648 |
| TEL | 35.760*** | 19.531 | 18.570 | 0.958 | 1.635 | 1.249 |
| CELL | 33.263*** | 17.378 | 22.374 | -3.497*** | -2.394*** | -2.252*** |
| GDP | 11.040 | 11.207 | 7.853 | 0.076 | -1.013 | -1.238 |
| $CO_2$ | 10.065 | 15.437 | 10.868 | 0.036 | -0.245 | -0.199 |
| URB | 142.15*** | 15.553 | 7.783 | -0.848 | -0.707 | -2.648 |
| TRADE | 6.061 | 9.805 | 10.423 | -0.292 | -2.622*** | -1.609** |

Source: Authors' computation. ***, **, * implies level of statistical significance at 1, 5 and 10%, respectively.
Note: INT, TEL and CELL represents internet usage, number of telephone lines and mobile cellular, respectively. CO2 implies carbon emissions, FD is financial development URB is urban population, while TRADE is trade openness.

**Table 3: Tests for cross-sectional dependence**

| Variable | CD-test | p-value |
|---|---|---|
| INT | 2.382 | 0.045 |
| FD | 19.394 | 0.036 |
| TEL | 333.847 | 0.394 |
| CELL | 2.781 | 0.023 |
| GDP | 13.304 | 0.573 |
| $CO_2$ | 23.394 | 0.042 |
| URB | 34.797 | 0.032 |
| TRADE | 22.3974 | 0.083 |

Source: Authors' computation

Note: INT, TEL and CELL represents internet usage, number of telephone lines and mobile cellular, respectively. CO2 implies carbon emissions, FD is financial development URB is urban population, while TRADE is trade openness.

**Table 4: Cointegration Results of Westerlund (2007)**

| | Stat | Z-Value | P-Value |
|---|---|---|---|
| $G_\tau$ | -4.024 | -9.135 | 0.000 |
| $G_\alpha$ | -27.256 | -10.545 | 0.000 |
| $P_\tau$ | -12.546 | -4.526 | 0.000 |
| $P_\alpha$ | -22.054 | -10.135 | 0.000 |

*Source: Authors' computation. $G_\tau$ and $G_\alpha$ are group mean statistics that test the null hypothesis of no cointegration against the alternative hypothesis of cointegration among some of the selected countries. $P_\tau$ and $P_\alpha$ are the panel statistics that test the null of no cointegration against the alternative.*

**Table 5: Baseline Results**

| | $CO_2$ | | | Economic Growth | | |
|---|---|---|---|---|---|---|
| Long Run | | | | | | |
| | PMG | MG | DFE | PMG | MG | DFE |
| FD | 0.130 (0.085) | 0.248 (0.144) | 0.058* (0.017) | -0.146 (0.203) | 0.012 (0.034) | 0.185 (0.076) |
| INT | 0.211** (0.086) | 0.347** (0.097) | 0.445*** (0.017) | -0.235 (0.321) | 0.211 (0.138) | -0.249 (0.186) |
| URB | -0.632*** (0.024) | -0.521** (0.096) | -0.266 (0.307) | 0.436** (0.103) | 0.335*** (0.054) | 0.155* (0.033) |
| TRADE | -0.058 (0.123) | -0.075 (0.049) | -0.106 (0.074) | -0.325 (0.284) | 0.154 (0.143) | 0.178* (0.048) |
| GDP | 0.125** (0.032) | 0.331* (0.103) | 0.106*** (0.011) | | | |
| $CO_2$ | | | | 0.551*** (0.016) | 0.325** (0.103) | 0.218*** (0.056) |
| Short Run | | | | | | |
| ECT | -0.121** (0.012) | - 0.213*** (0.003) | -0.458** (0.099) | -0.254** (0.087) | -0.385** (0.069) | -0.279** (0.076) |
| FD | 0.025* (0.008) | 0.014 (0.021) | -0.006 (0.009) | 0.061** (0.013) | 0.033 (0.045) | 0.019 (0.032) |
| INT | 0.005 (0.009) | -0.003 (0.008) | 0.015 (0.021) | -0.044 (0.075) | 0.068* (0.019) | 0.054 (0.077) |
| URB | -0.103 (0.100) | 0.099* (0.040) | -0.022 (0.017) | 0.064 (0.039) | 0.043 (0.071) | -0.027* (0.013) |
| TRADE | 0.011 (0.014) | 0.038* (0.023) | -0.004 (0.035) | 0.144*** (0.000) | 0.210** (0.08) | 0.311** (0.068) |
| GDP | 0.455** (0.146) | 0.327*** (0.004) | 0.181** (0.051) | | | |
| $CO_2$ | | | | 0.563** (0.143) | 0.419*** (0.028) | 0.214*** (0.017) |
| Haussman | 9.024 (0.556) | | | 10.465 (0.787) | | |

Source: Authors' computation. Note: *,**, and *** implies level of statistical significance at 10, 5 and 1% respectively. Values in parenthesis represent standard error statistics. ECT is the error correction term/speed of adjustment.

Note: INT, TEL and CELL represents internet usage, number of telephone lines and mobile cellular, respectively. CO2 implies carbon emissions, FD is financial development URB is urban population, while TRADE is trade openness.

**Table 6: Empirical Results (Internet Broadband)**

| | $CO_2$ | | | Economic Growth | | |
|---|---|---|---|---|---|---|
| | PMG | MG | DFE | PMG | MG | DFE |
| | | | Long Run | | | |
| FD | 0.127 (0.081) | 0.5001 (0.316) | -0.113*** (0.032) | -0.432* (0.238) | -0.187 (0.137) | 0.409 (0.471) |
| INT | 0.343*** (0.072) | 0.631** (0.297) | 0.105*** (0.039) | -0.231 (0.222) | -0.227 (0.153) | -0.159 (0.325) |
| URB | -0.011*** (0.001) | -0.080** (0.024) | -0.011*** (0.003) | 0.056*** (0.011) | 0.034* (0.019) | 0.017 (0.026) |
| TRADE | -0.002** (0.001) | -0.0001 (0.002) | -0.001 (0.002) | 0.005** (0.002) | 0.014 (0.010) | -0.009* (0.005) |
| INT*FD | 0.417*** (0.102) | -0.151** (0.069) | -0.019** (0.009) | -0.304** (0.054) | 0.059 (0.036) | 0.034 (0.065) |
| GDP | 0.306*** (0.082) | 0.888** (0.394) | -0.313** (0.123) | | | |
| $CO_2$ | | | | 0.759*** (0.168) | 0.518*** (0.159) | -1.109 (0.909) |
| | | | Short Run | | | |
| ECT | -0.666*** (0.155) | -0.943** (0.069) | -0.215*** (0.060) | -0.170*** (0.062) | -0.645*** (0.123) | -0.045** (0.021) |
| FD | 0.165* (0.096) | 0.053 (0.038) | 0.027 (0.029) | 0.026* (0.014) | 0.004 (0.021) | -0.001 (0.012) |
| INT | -0.004 (0.007) | 0.006 (0.012) | -0.011 (0.010) | -0.004 (0.005) | -0001 (0.006) | 0.010* (0.006) |
| URB | 0.029 (0.020) | -0.212 (0.239) | -0.012** (0.006) | -0.016 (0.035) | -0.026 (0.046) | -0.007 (0.007) |
| TRADE | 0.001 (0.002) | 0.001 (0.002) | -0.0001 (0.001) | 0.003*** (0.000) | 0.002*** (0.000) | 0.003*** (0.001) |
| INT*FD | -0.331 (0.078) | -0.101** (0.043) | -0.004** (0.002) | 0.062*** (0.023) | 0.021 (0.016) | -0.002 (0.002) |
| GDP | 0.413* (0.247) | -0.107 (0.369) | 0.760*** (0.141) | | | |
| $CO_2$ | | | | 0.0441 (0.061) | -0.109** (0.045) | 0.116* (0.062) |
| Haussman | 8.533 (0.741) | | | 2.344 (0.4875) | | |

*Source: Authors' computation. Note: *,**, and *** implies level of statistical significance at 10, 5 and 1% respectively. Values in parenthesis represent standard error statistics. ECT is the error correction term/speed of adjustment.*

**Table 7: Empirical Results for Robustness check (mobile cellular)**

| | $CO_2$ | | | Economic Growth | | |
|---|---|---|---|---|---|---|
| | PMG | MG | DFE | PMG | MG | DFE |
| | | | Long Run | | | |
| FD | 0.170 (0.123) | 0.660* (0.345) | -0.0588 (0.075) | 0.176 (0.276) | -0.111 (0.172) | 0.010 (0.333) |
| CELL | 0.357*** (0.106) | 0.871** (0.397) | 0.139** (0.068) | 0.374 (0.259) | -0.116 (0.218) | -0.414 (0.465) |
| URB | -0.009*** (0.002) | -0.039 (0.034) | - 0.009*** (0.003) | 0.057*** (0.010) | 0.030 (0.030) | 0.012 (0.021) |
| TRADE | -0.003*** (0.001) | -0.001 (0.001) | -0.001 (0.002) | 0.004** (0.002) | 0.002*** (0.000) | -0.012 (0.009) |
| CELL*FD | 1.135*** (0.232) | -0.202** (0.086) | -0.026* (0.015) | 0.386 (0.251) | 0.036 (0.046) | 0.097 (0.096) |
| GDP | 0.314*** (0.085) | 1.132*** (0.355) | -0.314** (0.123) | | | |
| $CO_2$ | | | | 0.659 (0.162) | 0.530*** (0.144) | -1.124 (0.893) |
| | | | Short Run | | | |
| ECT | -0.632*** (0.148) | -0.954*** (0.130) | - 0.201*** (0.066) | -0.185*** (0.062) | 0.732*** (115) | -0.045** (0.021) |
| FD | 0.182* (0.105) | 0.109* (057) | 0.025 (0.030) | 0.016 (0.013) | -0.007 (0.011) | -0.002 (0.012) |
| CELL | -0.020** (0.008) | 0.037 (0.034) | -0.013 (0.018) | 0.016* (0.009) | -0.006 (0.014) | 0.022** (0.008) |
| URB | 0.024 (0.018) | -0.044 (0.098) | -0.007 (0.005) | 0.0003 (0.035) | -0.091 (0.068) | -0.002 (0.004) |
| TRADE | 0.001 (0.002) | 0.001 (0.001) | -0.0001 (0.001) | 0.003*** (0.000) | 0.002*** (0.000) | 0.003*** (0.001) |
| CELL*FD | -0.771*** (0.181) | -0.190** (0.091) | -0.005 (0.003) | -0.084*** (0.028) | 0.011 (0032) | -0.004** (0.002) |
| GDP | 0.392 (0.247) | -0.264 (0.329) | 0.777*** (0.120) | | | |
| $CO_2$ | | | | 0.042 (0.060) | -0.139*** (0.049) | 0.113** (0.004) |
| Haussman | 8.533 (0.741) | | | 2.344 (0.4875) | | |

*Source: Authors' computation. Note: *,**, and *** implies level of statistical significance at 10, 5 and 1% respectively. Values in parenthesis represent standard error statistics. ECT is the error correction term/speed of adjustment.*

**Table 8: Empirical results (Robust fixed telephone)**

| | $CO_2$ | | | Economic Growth | | |
|---|---|---|---|---|---|---|
| | PMG | MG | DFE | PMG | MG | DFE |
| | | | Long Run | | | |
| FD | 0.204** (0.099) | 0.046* (0.171) | -0.142*** (0.051) | -0.346* (0.134) | 0.118 (0.082) | 0.381 (0.368) |
| TEL | -0.012 (0.012) | 0.005 (0.018) | 0.022*** (0.008) | -0.162 (0.110) | 0.028** (0.011) | 0.029 (0.043) |
| URB | -0.069*** (0.009) | -0.066*** (0.024) | -0.012*** (0.003) | 0.023** (0.005) | 0.018 (0.029) | 0.012 (0.020) |
| TRADE | -0.003*** (0.001) | -0.001 (0.002) | -0.001 (0.002) | 0.003*** (0.000) | 0.002* (0.001) | -0.010** (0.006) |
| TEL*FD | 11.935*** (1.016) | -0.003 (0.033) | -0.009 (0.014) | -0.203* (0.089) | -0.004 (0.007) | -0.021 (0.041) |
| GDP | 0.649*** (0.141) | 0.373 (0.360) | -0.281** (0.134) | | | |
| $CO_2$ | | | | 0.863*** (0.036) | 0.472*** (0.180) | -1.194** (0.522) |
| | | | Short Run | | | |
| ECT | -0.447** (0.206) | -0.963*** (0.168) | -0.192*** (0.067) | -0.229** (0.103) | -0.185*** (0.062) | -0.050** (0.019) |
| FD | 0.069 (0.070) | 0.079 (0.056) | 0.027 (0.010) | -0.084** (0.032) | 0.016 (0.013) | -0.003 (0.012) |
| TEL | 0.007 (0.018) | -0.059** (0.027) | -0.014 (0.010) | -0.038 (0.032) | 0.004 (0.011) | 0.021** (0.007) |
| URB | 0.147 (0.143) | -0.134 (0.108) | -0.013** (0.006) | -0.037** (0.012) | -0.081 (0.069) | -0.004 (0.006) |
| TRADE | 0.0002 (0.002) | 0.001 (0.002) | -0.0001 (0.001) | 0.013*** (0.0000) | 0.002*** (0.0006) | 0.003*** (0.001) |
| TEL*FD | -5.365** (2.474) | -0.021 (0.024) | -0.002 (0.003) | 0.043*** (0.002) | -0.004 (0.005) | -0.001 (0.002) |
| GDP | 0.642** (0.306) | 0.109 (0.248) | 0.797*** (0.117) | | | |
| $CO_2$ | | | | 0.372 (0.212) | -0.117*** (0.045) | 0.111* (0.059) |
| Haussman | 8.533 (0.741) | | | 2.344 (0.4875) | | |

*Source: Authors' computation. Note: *,**, and *** implies level of statistical significance at 10, 5 and 1% respectively. Values in parenthesis represent standard error statistics. ECT is the error correction term/speed of adjustment. Punishment*

## FIGURES

Figure 1: Baseline Results based on PMG results

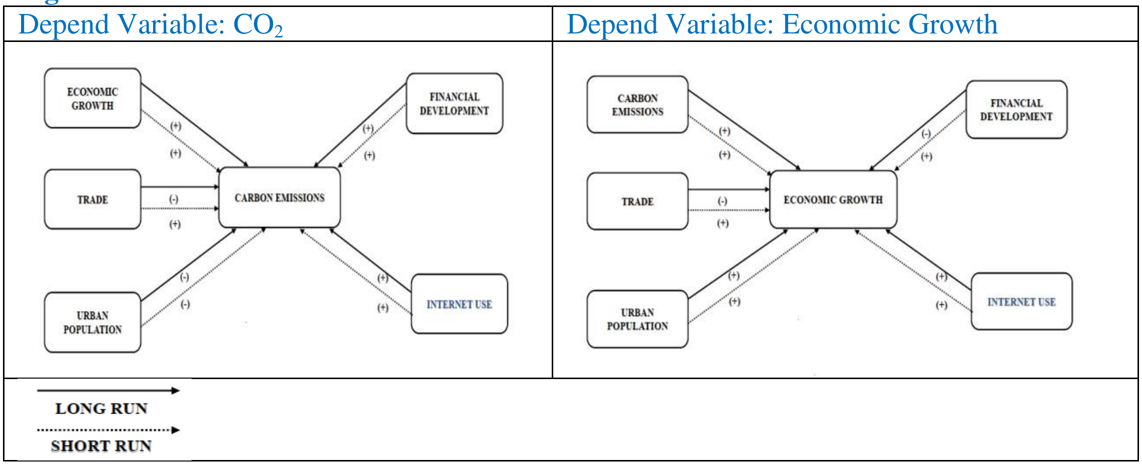
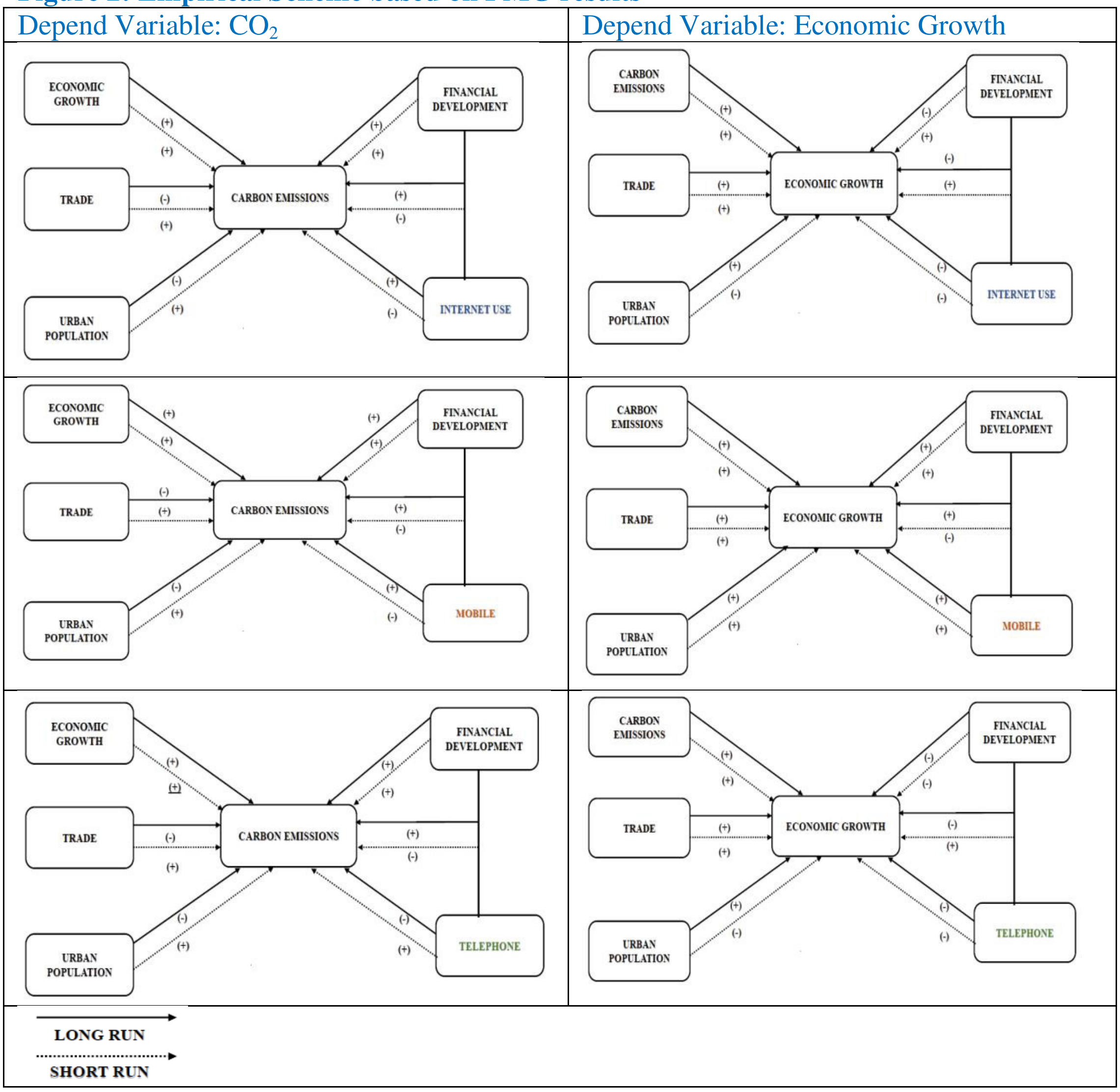



Figure 2: Empirical Scheme based on PMG results



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