The Impact of Information and Communication Technology on Carbon Emissions in Emerging Markets

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ABSTRACT

This study explored the influence of information and communication technology (ICT) on carbon emissions in emerging markets using panel data analysis methods (fixed effects, random effects, pooled OLS, FMOLS) with annual secondary data spanning from 1994 to 2014. Additionally, the study investigated whether financial development and economic growth are channels through ICT has an influence on carbon emissions. Without interaction terms, ICT was found to have had a significant positive influence on carbon emissions across all the four panel data analysis methods. After introducing interaction terms, financial development was found to be a channel through which ICT increased carbon emissions under the fixed effects, random effects and the FMOLS. Under the pooled OLS, financial development was found to be a channel through ICT enabled the reduction in carbon emissions. Economic growth was found to be a channel through ICT lowered down carbon emissions in emerging markets across all the four panel data analysis methods.

Keywords: Information and Communication Technology, Carbon Emissions, Financial Development, Growth, Emerging Markets
JEL Classifications: N7, P2

1. INTRODUCTION

The role of information and communication technology (ICT) on economic growth is a subject area that recently has been of interest to economists and policy makers. Theoretical and majority of empirical studies show that the ICT-led growth hypothesis is so dominant that the subject area is no longer contestable. Recent empirical studies which agrees with the ICT-led growth hypothesis include but are not limited to Niebel (2018), Jorgenson and Vu (2016), Nasab and Aghaei (2009), Albiman and Sulong (2016) and Vidas-Bubanja and Bubanja (2015). However, consistent with Khan et al. (2018), the environmental consequences of ICT are something that cannot be ignored. It is against this backdrop that recent empirical studies such as Khan et al. (2018), Lee and Brahmasrene (2014), Malmodin and Lunden (2018a), Asong (2018), Zhang and Liu (2015), Stewart (2015), Bekaroo et al. (2016), Hart (2016), Malmodin and Lunden (2016), Malmodin and Lunden (2018b),

Gelenbe and Caseau (2015), Al-Mulali et al. (2015), Coroama et al. (2012), Salahuddin et al. (2016), Ozcan and Apergis (2017), Lu (2018) and Higon et al. (2017) examined the impact of ICT on carbon emissions to try to understand the direct role that ICT has on the environment. The literature on ICT and carbon emissions is still very scant, not yet conclusive and there is no consensus yet.

Others argue that ICT increases carbon emissions (Zhang and Liu, 2015; Lee and Brahmasrene, 2014; Malmodin and Lunden, 2018a, others are of the view that ICT reduces carbon emissions (Zhang and Liu, 2015; Lee and Brahmasrene, 2014; Khan et al., 2018; Stewart, 2015; Hart, 2016) whilst the remainder supports the view that the impact of ICT on carbon emissions is still uncertain (Houghton, 2009). Bekaroo et al. (2016) supports the mixed view. The lack of clarity on the ICT-carbon emissions nexus can only be resolved through an empirical investigation.

Furthermore, most of these empirical studies assumed that there is a linear relationship between ICT and carbon emissions, an assumption which was proven to be untrue by Khan et al. (2018). Majority of the available empirical studies also focused on a single countries and used mobile telephones related proxies of ICT. The current study deviates from the existing empirical studies in the following ways: (1) It assumed that ICT and carbon emissions are related in a non-linear fashion by also investigating the impact of the interaction between (ICT and financial development) and (ICT and economic growth) on carbon emissions. (2) It focused on emerging markets, a list which is in line with International Monetary Fund (2015). (3) Used four panel data analysis methods (fixed effects, random effects, pooled OLS, FMOLS) to estimate the impact of ICT on carbon emissions. (4) The current study exclusively used internet penetration as a measure of ICT. (5) It investigated whether economic growth and financial development are channels through which ICT can influence carbon emissions in emerging markets, an objective which was also investigated by Khan et al. (2018) using different variables, proxies, methods and data set. The study helps emerging markets to develop ICT policies that reduces carbon emissions. It also helps emerging markets to develop financial development and economic growth policies that enhances ICT's ability to reduce carbon emissions.

Section 2 explains the theoretical literature on the impact of ICT on carbon emissions. Section 3 is the empirical literature review on the relationship between ICT and carbon emissions. Section 4 is the pre-estimation diagnostics. Section 5 explains the research methodology. Section 6 is data analysis, discussion and interpretation. The summary of the paper is in Section 7.

2. INFLUENCE OF ICT ON CARBON EMISSIONS- THEORETICAL LITERATURE

According to Zhang and Liu (2015), there are three theoretical rationales that describes the relationship between ICT and carbon emissions, namely (1) ICT-led carbon emissions hypothesis, (2) the optimistic view and (3) the uncertainty theoretical rationale. The ICT-led carbon emissions hypothesis argues that the continuous increase in the growth of the ICT sector is positively correlated with high energy consumption, which in turn lead to more carbon emissions. ICT has led to the use of many more electrical gadgets which uses energy hence more carbon emissions to an extent of endangering the initial goal of carbon emissions reduction.

The optimistic view states that the quantity of carbon emissions reduction triggered by ICT development is more than the direct effects of ICT towards carbon emissions. In other words, ICT contributes towards energy efficiency, less net energy consumption and carbon emissions (Zhang and Liu, 2015. p. 13; Lee and Brahmasrene, 2014. p. 97). Last but not least, the uncertainty theoretical rationale states that the relationship between ICT and carbon emissions is not clear because of the rebound effects. According to Houghton (2009), the reduction in carbon emissions due to ICT adoption is likely to dissipate as more and more ICT related gadgets continue to be used in people's everyday life.

3. ICT-CARBON EMISSIONS NEXUS –AN EMPIRICAL REVIEW

Khan et al. (2018) investigated the interrelationship between ICT, carbon emissions, financial development and economic growth using descriptive statistics (correlation matrix) and panel mean group estimation methods with data ranging from 1990 to 2015 in emerging economies. The findings were mainly two: (1) Economic growth led to the increase in carbon emissions, (2) the interaction between ICT and economic growth reduced the carbon emissions (pollution) and (3) whilst the interaction between ICT and financial development was found to have exacerbated the amount of carbon emissions in emerging markets.

Using panel data analysis with data spanning from 1991 to 2009, Lee and Brahmasrene (2014) explored the relationship between ICT, carbon emissions and economic growth for nine members from the Association of Southeast Asian Nations (ASEAN countries). The three variables were found to have a long run relationship. ICT was also found to have had a significant positive influence on both carbon emissions and economic growth. A study done by Malmodin and Lunden (2018a) also revealed that ICT usage had a positive impact on carbon emissions and electricity consumption globally.

Asong (2018) investigated the relationship between ICT, trade openness and carbon emissions in Sub-Saharan African countries using system generalised methods of moments (GMM) econometric estimation procedure with data ranging from 2000 to 2012. The findings showed that ICT was paramount in reducing the effects of environmental degradation such as carbon emissions in Sub Saharan African nations. Zhang and Liu (2015) on the other hand studied the direct impact of ICT adoption on carbon emissions in the Chinese regions. Their study used panel data analysis methods with Chinese's provincial data spanning from 2000 to 2010. Overall, ICT was found to have reduced carbon emissions in China. Another notable finding is that the deleterious effect of ICT on carbon emissions was found to be insignificant in the Western region, whilst it was higher in the central region as compared to the eastern region.

Using a case approach with a Latis model, Stewart (2015) found out that carbon emissions reduced in direct response to the implementation of ICT measures to improve bus journey times by the Scotland government. The study also revealed that ICT measures which in Scotland led to the decline in the number of cars used on the road and the consequent quantity of carbon emissions. Last but not least, Stewart (2015. p. 277) noted that the quantity of carbon emissions decline emanating from ICT'S efficient transport management was less than the quantity of carbon emissions reduction as a result of ICT's induced lower number of cars usage on the road. A study by Bekaroo et al. (2016) however highlighted mixed effects of ICT on carbon emissions. It showed that whilst ICT was traditionally viewed as a low carbon enabler, its widespread usage is now contributing to more energy use and carbon emissions (Bekaroo et al., 2016. p. 1580). Hart (2016) also noted that ICT efficiency as a result of using new computers led to a decline to the overall quantity of carbon gas emitted.

Malmodin and Lunden (2016) noted that ICT development reduced carbon emissions in the entertainment and media industry in Sweden mainly due to the gradual shift from computer usage to the use of smartphones which does not use a lot of energy. Malmodin and Lunden (2018b) also revealed that ICT led to a decline in carbon emissions in the entertainment and media sectors globally during the period from 2010 to 2015. Findings by Gelenbe and Caseau (2015) provide evidence that the impact of ICT on carbon emissions is mixed and also depends on the economic sectors involved. Al-Mulali et al. (2015) noted that the use of internet reduced carbon emissions in developed nations whilst the effect of internet retailing had an insignificant impact on carbon emissions in developing countries. Other empirical studies which observed that ICT reduced carbon emissions were done by Coroama et al. (2012), Salahuddin et al. (2016), Ozcan and Apergis (2017), Lu (2018) and Higon et al. (2017).

4. PRE-ESTIMATION DIAGNOSTICS

This section consists of ICT and carbon emission trends, descriptive and correlation statistics (Tables 1 and 2).

Ten countries (Czech Republic, Greece, Hong Kong, Malaysia, Poland, Portugal, Republic of Korea, Russia, Singapore and South Africa) had their mean carbon emissions greater than the overall mean carbon emissions of 5.42 metric tons per capita whilst the remaining eleven countries were characterised by mean carbon emissions which was lower than the overall mean carbon emissions value. Brazil, Colombia, Czech Republic, Indonesia, India, Peru, Philippines, Republic of Korea, Russia and South Africa were the outliers in the authors' view because their mean carbon emissions value deviated by a wider margin from the overall mean carbon emissions value of 5.42 metric tons per capita.

With regards to ICT, Czech Republic, Greece, Hong Kong, Malaysia, Poland, Portugal, Republic of Korea and Singapore were the emerging markets whose mean ICT penetration rates were greater than the overall mean ICT penetration figure of 24.16% of the population. Table 1 shows that Indonesia, India, Philippines, Republic of Korea, Thailand and South Africa are the outliers since their mean ICT penetration rates were found to have been far away from the overall mean ICT penetration rate. Only Brazil, Singapore, Republic of Korea, Turkey, Philippines, Colombia, and Greece and Indonesia were the only countries amongst those studied which cannot be regarded as outliers because their mean domestic credit by financial sector did not deviate too much from the overall mean domestic credit by financial sector of 82.32% of gross domestic product (GDP).

Emerging markets whose mean GDP per capita exceeded the overall mean GDP per capita of US$ 9 604.34 include Czech Republic, Greece, Hong Kong, Portugal, Republic of Korea and Singapore. Using the same argument as before, outliers in terms of GDP per capita include countries such as China, Colombia, Greece, Hong Kong, Indonesia, India, Peru, Philippines, Portugal, Republic of Korea, Thailand and Singapore.

Table 2 shows results of the descriptive statistics and correlation matrix. It is clear from Table 2 that economic growth data is an outlier since its corresponding standard deviation far much exceeds the 1 000 threshold alluded to by Tsaurai (2018a; b; c; d; e; f; g). It is also beyond any reasonable doubt that the data for all the variables used is not normally distributed because the probability of the Jarque-Bera criteria is exactly 0, in line with Tsaurai (2018b; c; d) observations.

The maximum size (ignoring the sign) of the correlation result is between FDI and trade openness (0.8070), evidence that the multi-

Table 1: ICT and carbon emission trends in emerging markets (1994-2014)

Countries	CO$_2$ emissions (metric tons per capita)	Individuals using internet (% of population)	Domestic credit by financial sector (% of GDP)	GDP per capita
Argentina	4.10	22.07	31.94	8 464.85
Brazil	1.94	21.30	79.68	6 601.52
China	4.53	15.17	128.30	2 612.19
Colombia	1.55	17.33	49.55	4 120.65
Czech Republic	11.29	36.20	56.39	12 718.56
Greece	8.00	25.49	105.48	19 694.43
Hong Kong	5.91	45.95	157.91	28 772.47
Indonesia	1.57	5.23	47.85	1 745.34
India	1.15	4.37	59.03	815.29
Mexico	4.01	16.98	37.24	7 396.19
Malaysia	6.46	35.79	132.99	6 321.99
Peru	1.35	17.26	19.92	3 401.58
Philippines	0.89	11.52	54.77	1 535.73
Poland	8.20	31.90	46.48	8 177.52
Portugal	5.37	31.10	143.14	17 116.92
Republic of Korea	9.89	54.88	114.80	17 097.56
Russia	11.29	21.00	31.89	6 383.08
Thailand	3.52	12.75	137.49	3 493.86
Turkey	3.61	19.50	50.42	6 525.40
Singapore	10.39	48.19	79.13	33 745.43
South Africa	8.77	13.35	164.40	6 483.85
Overall mean	5.42	24.16	82.32	9 604.34

Source: Author's compilation

Table 2: Descriptive statistics and correlation matrix

Descriptive statistics	CO₂	ICT	FIN	GROWTH	FDI	NAT	OPEN
Mean	5.42	24.16	82	9604.35	4.04	3.39	93.45
Median	4.52	14.74	65.99	5980.26	2.51	1.95	57.17
Maximum	18.04	87.56	236.45	56284.33	39.87	21.75	455.28
Minimum	0.77	0.00	10.81	353.29	0.03	0.01	15.64
Standard deviation	3.59	24.37	49.68	9829.91	5.76	4.07	95.27
Skewness	0.50	0.80	0.70	1.84	3.60	1.74	2.28
Kurtosis	2.27	2.38	2.42	7.01	17.47	6.11	7.39
Jarque-Bera	28.16	53.60	42.15	543.98	4800	398.61	737.14
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Observations	441	441	441	441	441	441	441
Correlation matrix							
CO₂	1.00						
ICT	0.3797***	1.00					
FIN	0.2261***	0.3547***	1.00				
GROWTH	0.4791***	0.6960***	0.3713***	1.00			
FDI	0.1699***	0.3712***	0.2570***	0.6283***	1.00		
NAT	0.0218	−0.0655	−0.1783***	−0.3498***	−0.1792***	1.00	
OPEN	0.3226***	0.4278***	0.3609***	0.6999***	0.8070***	−0.1892***	1.00

Source: Author compilation from E-Views. ***/**/*denotes statistical significance at the 1%/5%/10% level respectively

collinearity problem does not exist (Stead, 1996). Consistent with Tsaurai's (2018g) argument, all the data sets were transformed into natural logarithms before main data analysis was undertaken.

5. RESEARCH METHODOLOGY

$$CO2_{i,t} = \beta_0 + \beta_1 ICT_{i,t} + \beta_2 X_{i,t} + \mu_i + \varepsilon_{i,t} \qquad (1)$$

$CO2$, ICT and X represents carbon emissions, ICT and a X is a matrix of control variables respectively. In the current study, X contains financial development (FIN), economic growth (GROWTH), foreign direct investment (FDI), natural resources (NAT) and trade openness (OPEN). Consistent with Tsaurai (2019), the current study used economic growth, trade openness, foreign direct investment, natural resources and financial development as explanatory variables for the purposes of this study. $CO2$ emissions (metric tons per capita), individuals using internet (% of population), net FDI (% of GDP), domestic credit by financial sector (% of GDP), GDP per capita, total imports and exports (% of GDP) and total natural resources rents (% of GDP) are the respective measures for carbon emissions, ICT, FDI, FIN, GROWTH, OPEN and NAT that were used in this study.

Equation 2 captures the second objective whose aim is to investigate whether financial development and economic growth are channels through ICT affects carbon emissions.

$$CO2_{i,t} = \beta_0 + \beta_1 ICT_{i,t} + \beta_2 X_{i,t} + \beta_3 (ICT_{i,t}.x_{i,t}) + m_{i,t} \qquad (2)$$

In line with Goff and Singh (2014), $x_{i,t}$ corresponds to the level of financial development and economic growth in country i at time t.

Secondary annual data (1994-2014) whose sources include African Development Indicators, Global Development Indicators, International Monetary Fund and Word Development Indicators databases were used for the purposes of this study.

6. DATA ANALYSIS, DISCUSSION AND INTEPRETATION

CO_2, ICT, FIN, GROWTH, ICT*FIN, ICT*GROWTH, FDI, NAT and OPEN data were found to be stationary at their first differences or integrated of order 1 (Table 3). Such results allowed the author to proceed to panel co-integration analysis, consistent with Khan et al. (2018).

Using the Johansen Fisher Panel co-integration test (Table 4), the study found out that there were at most 6 co-integrating vectors between and among the variables studied.

Such a result confirms the existence of a long run relationship between and among the variables studied thus allowing the author to proceed to main data analysis (Table 5).

Across all the four panel data analysis methods used (fixed effects, random effects, pooled OLS, FMOLS), ICT had a significant positive effect carbon emission, consistent with Zhang and Liu (2015)'s theoretical rationale which says that a continuous increase in the growth of the ICT sector is positively correlated with high energy consumption, which in turn lead to more carbon emissions. A significant negative relationship running from financial development towards carbon emissions was detected under the fixed effects, random effects and the FMOLS, consistent with Yuxiang and Chen (2010) whose study revealed that the financial sector provided funding and technical assistance that enabled Chinese companies to adopt new and advanced technology that subsequently led to lower carbon emissions. Pooled OLS approach however produced results which shows that financial development increased carbon emissions, in line with Aye and Edoja's (2017) theoretical rationale that financial development increases carbon emissions because it attracts foreign investment firms which uses a lot of energy in their economic activities.

Table 3: Panel stationarity tests-individual intercept

Variables	Level				First difference			
	LLC	**IPS**	**ADF**	**PP**	**LLC**	**IPS**	**ADF**	**PP**
LCO_2	0.7706	3.0595	20.4777	21.5292	−7.7909***	−8.5182***	154.188***	309.187***
LICT	−18.618***	−15.436***	475.749***	1413.38***	−7.3378***	−4.5698***	99.7776***	145.853***
LFIN	−1.298*	1.2500	27.8542	21.1909	−5.0670***	−6.3582***	117.748***	355.172***
LGROWTH	1.4876	5.0440	9.5479	8.6597	−6.2515***	−6.2457***	113.462***	179.616***
LICT. LFIN	−15.981***	−11.903***	415.739***	651.860***	−5.3100***	−4.1083***	87.9471***	171.024***
LICT. LGROWTH	−16.827***	−13.134***	385.548***	824.988***	−7.165***	−4.659***	99.009***	152.770***
LFDI	−5.8469***	−5.5820***	104.312***	159.976***	−11.431***	−13.616***	241.383***	1573.63***
LNAT	−1.8629**	0.1528	27.092	33.344	−12.330***	−10.525***	176.286***	290.667***
LOPEN	−1.2281	0.9237	29.3499	59.9943**	−8.7965***	−9.2367***	163.976***	355.554***

Source: Author's compilation from E-Views. LLC, IPS, ADF and PP stands for Levin, Lin and Chu; Im, Pesaran and Shin; ADF Fisher Chi-square and PP Fisher Chi-square tests respectively.
*, ** and ***denote 1%, 5% and 10% levels of significance, respectively

Table 4: Johansen fisher panel co-integration test

Hypothesised no. of CE (s)	Fisher statistic (from trace test)	Probability	Fisher statistic (from max-eigen test)	Probability
None	24.95	0.9489	43.37	0.2529
At most 1	8.32	1.0000	247.8	0.0000
At most 2	333.0	0.0000	333.0	0.0000
At most 3	608.5	0.0000	362.9	0.0000
At most 4	328.4	0.0000	202.1	0.0000
At most 5	182.6	0.0000	139.6	0.0000
At most 6	119.3	0.0000	119.3	0.0000

Source: Author's compilation from E-views

Table 5: Impact of ICT on carbon emissions - main results

Variables	Carbon emissions			
	Fixed effects	**Random effects**	**Pooled OLS**	**FMOLS**
ICT	0.1414***	0.1447***	0.2144**	0.1151*
FIN	−0.0600*	−0.0584*	0.2025***	−0.1082*
GROWTH	0.2216***	0.2444***	0.71120***	0.2393***
FDI	0.0002	−0.0006	−0.1491***	0.0014
NAT	0.0331**	0.0130	0.0967***	0.0271
OPEN	0.0316	0.0838**	0.3134***	0.0862
ICT*FIN	0.0107**	0.0098*	−0.0341*	0.0082*
ICT*GROWTH	−0.0220***	−0.0223***	−0.0195*	−0.0181***
Number of countries	21	21	21	21
Adjusted R^2	0.9722	0.5783	0.5608	0.9806
F-statistic	550.30	59.39	71.21	-
Prob (F-statistic)	0.00	0.00	0.00	-

Source: Author's compilation from E-Views. LLC, IPS, ADF and PP stands for Levin, Lin and Chu; Im, Pesaran and Shin (2003); ADF Fisher Chi Square and PP Fisher Chi Square tests respectively. *, ** and *** denote 1%, 5% and 10% levels of significance, respectively

All the four econometric estimation methods used shows that economic growth had a significant positive influence on carbon emissions. In other words, economic growth was found to have increased the quantity of carbon emissions in emerging markets, a finding which resonates with Aye and Edoja (2017. p. 16) in the case of all developing countries. According to the fixed effects and FMOLS, FDI had an insignificant positive influence on carbon emissions, in support of Blanco et al.'s (2013) view. FDI had a negative but non-significant effect on carbon emissions under the random effects whilst a significant negative relationship running from FDI towards carbon emissions was observed under the pooled OLS. The results are in line with Cheng and Yang's (2016) findings.

In line with Kwakwa et al. (2018), natural resources had a (1) significant positive impact on carbon emissions under the fixed and pooled OLS and (2) a non-significant positive effect on carbon emissions under the random and FMOLS. Consistent with theoretical predictions, trade openness' positive impact on carbon

emissions was significant under the random and pooled OLS and non-significant under the fixed and FMOLS.

The impact of the interaction between ICT and financial development on carbon emissions was found to be positive and significant under the fixed effects, random effects and the FMOLS approaches. The finding means that financial development increased ICT's ability to generate more carbon emissions, in line with Khan et al. (2018. p. 22856). On the contrary, the influence of the interaction between ICT and financial development on carbon emissions had a significant negative effect on carbon emissions. The results mean that financial development enhanced ICT's ability to reduce carbon emissions, in line with the theoretical view by Yuxiang and Chen (2010) which says that the financial sector provides funding assistance that helps in the development of energy savings machinery and equipment thereby contributing towards lower carbon emissions. Last but not least, a significant negative relationship running from the interaction between ICT

and economic growth towards carbon emissions detected, a result which means that economic growth is a channel through which ICT reduced carbon emissions in emerging markets. The result resonates with Khan et al.'s (2018. p. 22856) findings.

7. CONCLUSION

This study explored the influence of ICT on carbon emissions in emerging markets using panel data analysis methods (fixed effects, random effects, pooled OLS, FMOLS) with annual secondary data spanning from 1994 to 2014. Additionally, the study investigated whether financial development and economic growth are channels through ICT has an influence on carbon emissions. Without interaction terms, ICT was found to have had a significant positive influence on carbon emissions across all the four panel data analysis methods. After introducing interaction terms, financial development was found to be a channel through which ICT increased carbon emissions under the fixed effects, random effects and the FMOLS. Under the pooled OLS, financial development was found to be a channel through ICT enabled the reduction in carbon emissions. Economic growth was found to be a channel through ICT lowered down carbon emissions in emerging markets across all the four panel data analysis methods.

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