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ICT, Openness and CO_2 emissions in Africa

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Abstract

This study investigates how information and communication technology (ICT) complements globalisation in order to influence CO_2 emissions in 44 Sub-Saharan African countries over the period 2000-2012. ICT is measured with internet penetration and mobile phone penetration whereas globalisation is designated in terms of trade and financial openness. The empirical evidence is based on the Generalised Method of Moments. The findings broadly show that ICT can be employed to dampen the potentially negative effect of globalisation on environmental degradation like CO_2 emissions. Practical, policy and theoretical implications are discussed.

JEL Classification: C52; O38; O40; O55; P37
Keywords: CO2 emissions; ICT; Economic development; Africa

1. Introduction

Four main points motivate the positioning of this inquiry. They are: (i) the great potential of information and communication technology (ICT) penetration in Sub-Saharan Africa (SSA); (ii) issues of global warming and environmental sustainability; (iii) the role of globalisation in driving environmental degradation such as carbon dioxide (CO_2) emissions and (iv) gaps in the literature. These four ideas are discussed in chronological order.

First, consistent with recent ICT literature, there is considerable room for ICT penetration in SSA when the region is compared with more advanced economies in Asia, Europe and North America where the penetration of ICT has reached saturation levels (see Penard *et al.*, 2012; Asongu, 2013; Tchamyou, 2016; Asongu, 2017). This potential for penetration can be leveraged by policy makers in order to tackle glaring policy issues in the sustainable development era like environmental pollution and global warming.

Second, in the post-2015 development era, environmental sustainability is centred on the policy agenda (Asongu *et al.*, 2016a). There are at least four main reasons why we should be concerned with environmental sustainability in SSA. They include: (i) the impressive growth record registered over the past two decades after lost decades driven by Structural Adjustment Programmes (see Fosu, 2015). Consequently, the continent currently hosts seven of the ten fastest growing countries in the world (Asongu & Rangan, 2016). (ii) The persistent energy crisis which represents one of the most critical challenges in the post-2015 development agenda (Akinyemi *et al.* (2015). To put this point into perspective, only 5 percent of SSA has access to energy (Shurig, 2015). According to the narrative, the total energy consumption in SSA is equivalent to that consumed by the State of New York in the United States of America (USA). Moreover, the energy consumption in the sub-region is below 17 percent of the global average. (iii) The poor energy management which characterizes most African countries (see Anyangwe, 2014). For example in Nigeria, fossil fuels are subsidized by the government and less emphasis is placed on renewable energy sources. According to Apkan and Apkan (2012), shortages in electricity production are compensated by over reliance on imported petroleum fuel. (iv) The negative consequences of global warming are the primary concerns in the post-2015 sustainable development agenda. According to Huxster *et al.* (2015), these problems are direct outcomes of the unsustainable consumption of fossil fuels. Moreover, Kifle (2008) argued that Africa will be the continent most negatively affected by the adverse effects of global warming. This position is broadly consistent with Akpan and Akpan (2012) who assert that CO_2 emissions account for about three-quarters of world emissions in greenhouse gases.

Third, CO_2 emissions have been fuelled by globalization (Peters & Hertwich, 2008; Hertwich & Peters, 2009). There is a clear link between global trade and the carbon footprint of nations. Such CO_2 emissions embodied in international trade have implications for global climate policy because the pollution via international trade flows substantially undermines environmental policies, especially for global pollutants (see Peters & Hertwich, 2008).

This current study unites the three strands above by assessing how ICT can be tailored to reduce the potential negative effects of globalization on CO_2 emissions. The intuition for employing ICT to dampen CO_2 resulting from globalization follows from two key ideas. They comprise that ICT can (i) prevent unnecessary travelling and (ii) help corporations and households to efficiently consolidate the management of their financial affairs. These propositions fall within the framework of theory-building because we intend to provide empirical evidence with related policy implications. Hence, we join Narayan *et al.* (2011) in arguing that applied econometrics should not be exclusively based on the acceptance or rejection of existing theoretical underpinnings. This is because an empirical exercise based on sound hypothesis may lead to theory-building, especially for a new phenomenon like the interaction between economic activities and ICT on CO_2 emissions.

The positioning of this paper steers clear of recent literature on CO_2 emissions which for the most part has focused on relationships between CO_2 emissions, energy consumption and economic growth. The underlying literature has been dominated by two fundamental strands. The *first* focuses on the relationship between economic growth and environmental pollution with a great deal of emphasis on examining the Environmental Kuznets Curve (EKC) hypothesis (see Diao *et al.*, 2009; Akbostanci *et al.*, 2009; He & Richard, 2010)[1]. Two main themes make-up the *second* strand: (i) relationships between energy consumption, environmental pollution and economic growth (Jumbe, 2004; Ang, 2007; Odhiambo, 2009a, 2009b; Apergis & Payne, 2009; Menyah & Wolde-Rufael, 2010; Ozturk & Acaravci, 2010; Bölük & Mehmet, 2015; Begum *et al.*, 2015) and (ii) linkages between the consumption of energy and economic growth (Mehrara, 2007; Esso, 2010).

[1] According to the EKC hypothesis, in the long term, there is an inverted U-shaped relationship between per capita income and environmental degradation. It is important to note that, the paragraph highlighting the extant literature involves some grouping of it on "CO_2 emissions, energy consumption and economic growth" into two main strands. Literature on the EKC is categorized in one of the strands. This categorization which is based on broader literature than the EKC scope is not exhaustive and does not negate the fact that there are two main branches of the literature on the EKC.

A fundamental shortcoming in the highlighted studies is that they collectively fail to include a policy variable with which CO_2 emissions can be mitigated in order to improve environmental sustainability. In this study, we argue that findings based on linkages between growth, CO_2 emissions and energy consumption have limited practical significance if policy makers are not provided with instruments by which policy syndromes (such as CO_2 emissions) can be curbed.

This study fills the highlighted gap by employing ICT as the policy variable in the relationship between globalisation and CO_2 emissions. To make this assessment, trade and financial globalisation variables are interacted with internet and mobile phone penetrations in order to assess the net effect on CO_2 emissions. The net impacts are computed from both the conditional and unconditional effects of ICT. Hence, the inquiry steers clear of recent ICT literature which has fundamentally focused on among others economic prosperity (Qureshi, 2013a; Levendis & Lee, 2013); banking sector progress (Kamel, 2005); living standards (Chavula, 2013); externalities in welfare (Qureshi, 2013b, 2013c; Carmody, 2013); Africa's information revolution from the perspectives of production networks and technical regimes (Murphy & Carmody, 2015); life for all (Ponelis & Holmner, 2013a, 2013b; Kivuneki *et al.*, 2011) and sustainable development (Byrne, 2011) in developing nations. Accordingly, while socioeconomic and human development benefits from ICT have been well established in the literature, very little is known about the connections between ICT, openness and aspects of environmental sustainability like CO_2 emissions[2].

It is important to articulate why ICT is related to sustainable development and climate change. According to Amavilah *et al.* (2017), for sustained development to be sustainable, it must be inclusive, while for inclusive development to be sustainable it should be sustained over a reasonable time period. CO_2 emissions and sustainable development are connected in the view that ICT can be used to mitigate CO_2 emissions by means of *inter alia*: (i) decreasing transport cost that is unnecessary and (ii) improving the management and consolidation of both businesses and households' financial affairs. For instance, Hilty *et al.* (2006) have established that ICT improves the efficiency of energy in production processes and enhances environmental friendly shifts in the consumption of commodities as well as positive sustainable development externalities in the transport sector. Such potential reductions in CO_2

[2] The positioning of the study departs from recent African literature on the employment of ICT development purposes (Kuada, 2009, 2014, 2015; Afutu-Kotey *et al.*, 2017) and social change (Tony & Kwan, 2015; Gosavi, 2017; Minkoua Nzie et al., 2017).

emissions ultimately have a favourable effect on climate change in the perspective of reducing global warming.

The underlying link between ICT and sustainable development is consistent with literature on: enhancing ICT for environmental sustainability (Asongu *et al.*, 2018; Hign *et al.*, 2017); the employment of ICT to mitigate the potentially negative effects of environmental degradation on inclusive human development (Asongu *et al.*, 2017) and ICT-led energy management which is essential for structural transition towards economies that are less material-intensive and cost and time saving for transport (Hilty *et al.*, 2006).

The positioning of the paper also departs from recent literature on environment sustainability which has focused primarily on: decomposing inequality in CO_2 emissions that are related to energy (Chen *et al.*, 2017); the conduciveness of CO_2-related to plastic products (Van Heek *et al.*, 2017); CO_2 abatement and renewable energy (Marcantonini & Valero, 2017); economic impacts from the implementation of programmes on energy efficiency (Martinez *et al.*, 2017) and computation of CO_2 emissions within an added value framework (Xu *et al.*, 2017).

The rest of the study is structured as follows. Section 2 describes the data and methodology. The empirical results are presented in Section 3 whereas Section 4 concludes with policy implications and future research directions.

2. Data and methodology

This study investigates a panel of 44 nations in SSA with data from the African Development Indicators of the World Bank for the period 2000-2012[3]. Whereas the scope of the inquiry is in line with the motivation in the introduction, the corresponding periodicity is contingent on constraints in data availability. The dependent variable is CO_2 emissions per capita. In the corresponding assessment, a negative effect on the outcome variable is an indication of favourable conditions for environmental protection or sustainability.

ICT is measured with mobile phone and internet penetration whereas globalisation embodies both financial (or foreign direct investment) and trade (imports plus exports of commodities). The choice of the ICT and globalisation variables is consistent with recent literature (Penard *et al.*, 2012; Asongu, 2014; Amavilah *et al.*, 2017; Tchamyou, 2016).

[3] The 44 countries are: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo Democratic. Republic., Congo Republic, Cote d'Ivoire, Djibouti, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome & Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda and Zambia.

Hence, the internet penetration rate (per 100 people) and mobile phone penetration rate (per 100 people) are used as ICT policy variables.

Four control variables are employed in order to avoid variable omission bias. They comprise: (i) Gross Domestic Product (GDP) growth rate, (ii) Population growth rate, (iii) Educational quality and (iv) Regulation quality. Whereas we intuitively expect the first-two variables to positively influence CO_2 emissions, the last-two should have the opposite effect. However, it is important to note that growth which is not broad-based, but limited to selected extractive industries, may not have the expected effect. Moreover, expected signs may be contingent on the influence of country-specific characteristics that are not considered in the specification of the Generalised Method of Moments (GMM). The full definitions of variables, corresponding summary statistics and correlation matrix are disclosed in Appendix 1, Appendix 2 and Appendix 3 respectively. The concern about a high correlation between ICT variables is solved by employing the ICT variables in distinct specifications.

A *two-step* GMM estimation approach is adopted for five fundamental reasons: (i) the number of countries (44) is higher than the number of years in each country (13); (ii) the CO_2 emission variable is persistent because its correlation coefficients with its first lag is higher than the rule thumb threshold of 0.800; (iii) given that the GMM approach is consistent with a data structure which by definition should be panel, cross-country variations are taken into account in the regressions; (iv) the estimation approach further deals with simultaneity bias in the exploratory variables by a process of instrumentation as well as by use of time-invariant variables and (v) inherent biases in the *difference* estimator are corrected with the *system* estimator.

In this study, we employ the Roodman (2009a, 2009b) extension of Arellano and Bover (1995) because, relative to traditional GMM techniques (*difference* and *system* GMM approaches), it mitigates the proliferation of instruments (or restricts over-identification) and accounts for cross-sectional dependence (Love & Zicchino, 2006; Baltagi, 2008; Boateng *et al.*, 2018).

The following equations in level (1) and first difference (2) summarise the standard *system* GMM estimation procedure.

$$CO_{i,t} = \sigma_0 + \sigma_1 CO_{i,t-\tau} + \sigma_2 G_{i,t} + \sigma_3 I_{i,t} + \sigma_4 GI_{i,t} + \sum_{h=1}^{4} \delta_h W_{h,i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t}$$

(1)

$$CO_{i,t} - CO_{i,t-\tau} = \sigma_1(CO_{i,t-\tau} - CO_{i,t-2\tau}) + \sigma_2(G_{i,t} - G_{i,t-\tau}) + \sigma_3(I_{i,t} - I_{i,t-\tau}) + \sigma_4(GI_{i,t} - GI_{i,t-\tau}) + \sum_{h=1}^{4}\delta_h(W_{h,i,t-\tau} - W_{h,i,t-2\tau}) + (\xi_t - \xi_{t-\tau}) + \varepsilon_{i,t-\tau}$$

(2)

where, $CO_{i,t}$ is a CO_2 emissions indicator of country i at period t, σ_0 is a constant, G represents globalisation (trade openness and foreign direct investment), I is information and communication technology (mobile phone penetration and internet penetration), GI is the interaction between a globalisation variable and an ICT policy variable, W is the vector of control variables (*GDP growth*, *population growth*, *education* and *regulation quality*), τ represents the coefficient of auto-regression which is one for the specification, ξ_t is the time-specific constant, η_i is the country-specific effect and $\varepsilon_{i,t}$ the error term.

It is important to briefly discuss properties related to identification and exclusion restrictions because these are critical for acceptable GMM specifications. Consistent with recent literature, all explanatory variables are considered as endogenous while only time-invariant indicators are acknowledged to be strictly exogenous. This identification strategy has been recently adopted by Boateng *et al.* (2016) plus Asongu and Nwachukwu (2016b). It is important to note that Roodman (2009b) has argued that it is not likely for time-invariant variable to reflect endogeneity after first difference[4].

With regards to exclusion restrictions, in the light of the identification process above, time invariant variables influence CO_2 emissions exclusively through the endogenous variables. Moreover, the statistical validity of the suggested exclusion restriction is investigated with the Difference in Hansen Test (DHT) for instrument exogeneity. Under this framework, the null hypothesis of the DHT should not be rejected in order for the exclusion restriction hypothesis to hold, notably: the time invariant omitted variables affecting CO_2 emissions exclusively via suspected endogenous variables. Therefore, in the findings that are reported in the empirical results section, the assumption of exclusion restriction is confirmed if the null hypothesis of the DHT related to instrumental variables (IV) (year, eq(diff)) is not rejected. This process of assessing the validity of exclusion restriction is not different from the standard IV procedure whereby, the failure to reject the null hypothesis of the Sargan Overidentifying Restrictions (OIR) test is an indication that strictly exogenous variables affect

[4] Hence, the procedure for treating *ivstyle* (years) is 'iv (years, eq(diff))' whereas the *gmmstyle* is employed for predetermined variables.

CO_2 emissions exclusively via the suspected endogenous variable mechanisms (see Beck *et al.*, 2003; Asongu & Nwachukwu, 2016c).

3. Empirical results

Table 1 below presents the empirical results. There are two main sets of specifications: one without the conditioning information set (or set of control variables) and the other with the conditioning information set. Each set of specifications entails four subsets of specifications: two pertaining to trade openness and two relating to financial openness. Moreover, each sub-specification is characterised with 'mobile phone'- and 'internet'-related regressions.

Four principal information criteria are used to investigate if the GMM models are valid[5]. In addition to the information criteria, two points are worthy of note. (i) The second-order Arellano and Bond autocorrelation test (AR[2]) is more relevant as an information criterion than the corresponding first-order test because some studies have exclusively reported a higher order with no disclosure of the first order (e.g. see Narayan *et al.*, 2011; Asongu & Nwachukwu, 2016d). (ii) The Sargan test is not robust but not weakened by instruments whereas the Hansen test is robust but weakened by instruments. A logical way of addressing the conflict is to adopt the Hansen test and avoid the proliferation of instruments. Instrument proliferation is subsequently avoided by ensuring that the number of instruments in each specification is lower than the corresponding number of cross sections.

Net effects are computed to examine the overall impact of the complementarity between the ICT policy variable and globalisation in CO_2 emissions. For instance, in the second-to-the last column of Table 1, the net impact from the interaction between mobile phones and trade is -0.0012([-0.00009× 24.428] + [0.001]). In the computation, the mean value of mobile phone penetration is 24.428, the unconditional effect of mobile phone penetration is 0.001 while the conditional effect from the interaction between trade openness and mobile phones is -0.00009.

The following findings can be established from the table. (i) In spite of negative conditional effects in regressions without a conditioning information set, the net effects are

[5] "*First, the null hypothesis of the second-order Arellano and Bond autocorrelation test (AR [2]) in difference for the absence of autocorrelation in the residuals should not be rejected. Second the Sargan and Hansen over-identification restrictions (OIR) tests should not be significant because their null hypotheses are the positions that instruments are valid or not correlated with the error terms. In essence, while the Sargan OIR test is not robust but not weakened by instruments, the Hansen OIR is robust but weakened by instruments. In order to restrict identification or limit the proliferation of instruments, we have ensured that instruments are lower than the number of cross-sections in most specifications. Third, the Difference in Hansen Test (DHT) for exogeneity of instruments is also employed to assess the validity of results from the Hansen OIR test. Fourth, a Fischer test for the joint validity of estimated coefficients is also provided*" (Asongu & De Moor, 2017, p.200).

not apparent because at least one of the estimated coefficients needed for the computation of nets effects is not significant. (ii) Concerning regressions with a conditioning information set, whereas all conditional effects are consistently negative, net effects from two specifications are also negative, notably, from the interaction: between trade openness and internet penetration on the one hand and on the other hand, between mobile phone penetration and financial openness. Most of the control variables are significant with the expected signs.

Table 1: ICT, Openness and CO_2 emissions

	CO_2 emissions (metric tons per capita)							
	Without a Conditioning Information Set				Without a Conditioning Information Set			
	Trade Openness		Financial Openness		Trade Openness		Financial Openness	
	Mobile	Internet	Mobile	Internet	Mobile	Internet	Mobile	Internet
Constant	-0.051	0.026	**0.033****	**0.061****	**0.261*****	**0.502*****	**0.318*****	**0.402*****
	(0.513)	(0.375)	**(0.036)**	**(0.010)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
CO_2 emissions per capita	**0.911*****	**0.949*****	**0.929*****	**0.881*****	**0.942*****	**0.917*****	**0.900*****	**0.931*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Mobile	0.001	---	**0.001*****	---	**0.002****	---	**0.001*****	---
	(0.341)		**(0.000)**		**(0.010)**		**(0.004)**	
Internet	---	**0.007***	---	**0.007*****	---	**0.020*****	---	**0.003*****
		(0.091)		**(0.000)**		**(0.000)**		**(0.000)**
Trade	0.0001	-0.00005	---	---	-0.0001	**-0.001*****	---	---
	(0.871)	(0.915)			(0.603)	**(0.000)**		
FDI	---	---	0.0003	0.00008	---	---	**0.001*****	0.0004
			(0.664)	(0.883)			**(0.003)**	(0.334)
Mobile.Trade	0.000005	---	---	---	**-0.00002*****	---	---	---
	(0.804)				**(0.000)**			
Mobile.FDI	---	---	-0.00001	---	---	---	**-0.00009*****	---
			(0.614)				**(0.000)**	
Internet.Trade	---	**-0.00007****	---	---	---	**-0.0001*****	---	---
		(0.011)				**(0.000)**		
Internet.FDI	---	---	---	**-0.0001*****	---	---	---	**-0.001*****
				(0.000)				**(0.000)**
GDP growth	---	---	---	---	-0.0008	-0.001	**-0.002****	**-0.003*****
					(0.545)	(0.142)	**(0.011)**	**(0.003)**
Popg	---	---	---	---	**-0.068*****	**-0.084*****	**-0.117*****	**-0.094*****
					(0.000)	**(0.000)**	**(0.000)**	**(0.000)**
Education	---	---	---	---	**-0.002****	**-0.004*****	**-0.0004**	**-0.002*****
					(0.012)	**(0.000)**	**(0.510)**	**(0.000)**
Reg. Quality	---	---	---	---	**-0.102*****	-0.039	-0.009	**0.034***
					(0.007)	(0.273)	(0.578)	**(0.051)**
Net Effects	na	na	na	na	na	-0.0014	-0.0012	na
AR(1)	**(0.145)**	**(0.145)**	**(0.142)**	**(0.144)**	(0.094)	(0.095)	**(0.109)**	(0.094)
AR(2)	**(0.253)**	**(0.339)**	**(0.250)**	**(0.380)**	**(0.207)**	**(0.148)**	**(0.196)**	**(0.157)**
Sargan OIR	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Hansen OIR	**(0.810)**	**(0.529)**	**(0.359)**	**(0.376)**	**(0.885)**	**(0.739)**	**(0.502)**	**(0.455)**
DHT for instruments								
(a)Instruments in levels								
H excluding group	**(0.221)**	**(0.479)**	**(0.225)**	**(0.496)**	**(0.094)**	**(0.400)**	**(0.725)**	**(0.427)**
Dif(null, H=exogenous)	**(0.976)**	**(0.478)**	**(0.469)**	**(0.301)**	**(0.207)**	**(0.811)**	**(0.329)**	**(0.447)**
(b) IV (years, eq(diff))								
H excluding group	na	na	na	na	(0.000)	**(0.531)**	**(0.535)**	**(0.230)**
Dif(null, H=exogenous)	**(0.810)**	**(0.529)**	**(0.359)**	**0.376**	**(0.885)**	**(0.792)**	**(0.401)**	**(0.768)**
Fisher	**3630*****	**32611*****	**10070*****	**25312*****	**25494*****	**154375*****	**84665*****	**452624*****
Instruments	25	25	25	25	40	40	40	40
Countries	44	44	44	44	44	43	44	43
Observations	468	464	469	465	339	334	340	335

*,**,***: significance levels of 10%, 5% and 1% respectively. DHT: Difference in Hansen Test for Exogeneity of Instruments' Subsets. Dif: Difference. OIR: Over-identifying Restrictions Test. The significance of bold values is twofold. 1) The significance of estimated coefficients and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) and AR(2) tests and; b) the validity of the instruments in the Sargan and Hansen OIR tests. na: not applicable because at least one estimated coefficient needed for the

computation of net effects is not significant. The mean of mobile phone penetration is 24.428 while the mean of internet penetration is 4.222.

4. Concluding implications and future research directions

This study has examined how information and communication technology (ICT) complements globalisation in order to influence CO_2 emissions in 44 Sub-Saharan African countries for the period 2000-2012. ICT is measured with internet penetration and mobile phone penetration whereas globalisation is represented in terms of trade openness and financial openness. The empirical evidence is based on the Generalised Method of Moments. The findings have broadly shown that ICT can be employed to dampen the potentially negative effect of globalisation on environmental degradation like CO_2 emissions. In what follows, we discuss practical, policy and theoretical implications of findings.

As for the practical implications, the results suggest that ICT can substantially reduce the costs and constraints associated with globalisation activities that produce CO_2 emissions. The relevance of ICT in dampening globalisation-driven CO_2 emissions is largely consistent with the literature maintaining that ICT through network avenues decrease cost/traffic per minute associated with economic activities (Gille *et al*., 2002; Esselaar *et al*., 2007; Gutierrez *et al*., 2009; Gilwald & Stork, 2008). For example, the mobile phone that is connected to the internet can be used to make a quick communication which can save energy and transport expenditure from globalization-related activities. Such reduction in cost is a positive function of CO_2 emissions.

The main practical implication from the study is that ICT can be consolidated in order to ameliorate globalisation activities that increase CO_2 emissions. Therefore, in the post-2015 sustainable development era, it is relevant for countries to address concerns that are related to ICT infrastructure as well as anxieties linked to the affordability of ICT. By addressing such critical ICT access barriers, CO_2 emissions would be sustainably reduced. Moreover, schemes that encourage low pricing and universal coverage would also go a long way to tackling global warming and associated negative externalities. In a nutshell, the discussed advantages can be enhanced if ICT policies are designed to boost, among others: access, adoption, reach, interactions and effectiveness. The recommendations also accord with the policy perspective that the World Trade Organisation (WTO) can ensure that trade policies enhance ecological sustainability by committing to effective coordination in the environmental arena (Chemutai, 2009). We have established that the employment of ICT for such coordination is a step in the right direction.

The main theoretical contribution of this study is that ICT acts as an information sharing mechanism by reducing globalization-related information asymmetry which is related to the emission of green house gases. Thus, by reducing informational rents that are linked with CO_2 emissions and environmental degradation, the theoretical role of ICT is broadly consistent with the theoretical mission of information sharing offices (public credit registries and private credit bureaus) in mitigating information asymmetry for financial intermediation efficiency in the banking industry (see Triki & Gajigo, 2014; Tchamyou & Asongu, 2017). Therefore, with the above analogy in mind, the theoretical background for improving financial efficiency by means of information sharing offices is broadly in accordance with the spirit of using ICT to dampen informational rents or information asymmetry that encourage globalisation-driven CO_2 emissions.

In order to improve existing knowledge, it is worthwhile that future studies investigate whether the established findings withstand empirical scrutiny within country-specific frameworks. Such extensions are relevant for more targeted policy implications.

Appendices

Appendix 1: Variable Definitions

Variables	Signs	Variable Definitions (Measurement)	Sources
CO_2 per capita	CO2mtpc	CO_2 emissions (metric tons per capita)	World Bank (WDI)
Educational Quality	Educ	Pupil teacher ratio in Primary Education	World Bank (WDI)
Internet	Internet	Internet penetration (per 100 people)	World Bank (WDI)
Mobile phones	Mobile	Mobile phone subscriptions (per 100 people)	World Bank (WDI)
GDP growth	GDPg	Gross Domestic Product (GDP) growth (annual %)	World Bank (WDI)
Population growth	Popg	Population growth rate (annual %)	World Bank (WDI)
Foreign investment	FDI	Foreign Direct Investment inflows (% of GDP)	World Bank (WDI)
Trade Openness	Trade	Imports plus Exports of goods and services (% of GDP)	World Bank (WDI)
Regulation Quality	RQ	"Regulation quality (estimate): measured as the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development"	World Bank (WDI)

WDI: World Bank Development Indicators.

Appendix 2: Summary statistics (2000-2012)

	Mean	SD	Minimum	Maximum	Observations
CO_2 per capita	0.901	1.820	0.016	10.093	567
Mobile phone penetration	24.428	28.535	0.000	147.202	525
Internet Penetration	4.222	6.618	0.005	43.605	521
Foreign Direct Investment inflows	5.279	8.639	-6.043	91.007	566
Trade Openness	76.881	35.326	20.964	209.874	555
GDP growth	4.851	5.000	-32.832	33.735	567
Population growth	2.334	0.866	-1.081	6.576	529
Educational Quality	43.784	14.731	12.466	100.236	425
Regulation Quality	-0.607	0.544	-2.238	0.983	530

S.D: Standard Deviation.

Appendix 3: Correlation matrix (uniform sample size: 155)

CO2mtpc	Internet	Mobile	FDI	Trade	GDPg	Popg	Educ	RQ	
1.000	0.411	0.558	-0.148	-0.0004	-0.057	-0.611	-0.369	0.593	CO2mtpc
	1.000	0.718	-0.022	0.256	0.021	-0.580	-0.444	0.536	Internet
		1.000	0.096	0.270	-0.128	-0.580	-0.403	0.505	Mobile
			1.000	0.386	0.107	0.064	0.123	-0.244	FDI
				1.000	-0.136	-0.406	-0.147	0.128	Trade
					1.000	0.074	0.104	-0.140	GDPg
						1.000	0.515	-0.624	Popg
							1.000	-0.515	Educ
								1.000	RQ

CO2mtpc: CO_2 emissions (metric tons per capita). Educ: Quality of primary education. Internet: Internet penetration. GDPg: GDP growth. Popg: Population growth. FDI: Foreign Direct Investment inflows. RQ: Regulation Quality. Mobile: Mobile Phone penetration.

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