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Moving Toward Environmental Sustainability: ICTs, Freight Transport, and CO_2 Emissions

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Abstract

The link between ICTs, freight transport, and CO_2 emissions has not received much explicit examination by researchers, despite freight transportation being an egregious contributor to environmental degradation. This paper investigates how ICTs can affect environmental quality when interacting with freight transport activities in 43 countries over the period 2002-2014, using carbon emissions as a proxy for environmental damages. ICTs are measured in terms of internet, telephone, and mobile phone technologies. Using GMM methodology, the results show that ICTs contribute to dampening environmental degradation when interacting with freight transport activities. Specifically, a 10% increase in the interaction between ICTs and freight transportation will decrease carbon emissions by between 1.27% and 3.02%. The results further suggest that fixed and smartphone technologies are the main contributors to reducing emissions when adopted in some specific transport sectors (i.e. road, rail, and inland), while the internet is the most efficient technology when interacting with air transport activity. In addition, the interaction between ICTs and multimodality accelerates environmental quality. The policy implications of these findings are discussed.

Keywords: ICTs, Freight transport, CO_2 emissions, Environment, Panel data

1. Introduction

Transport systems actively contribute to the socio-economic development of countries. Freight transport essentially facilitates access to goods and materials, comprising the main distribution channels of imports and exports. However, freight activity is a major contributor to global atmospheric pollution, especially the road transport sector, and if the average global temperature increases by 2ºC, the impacts are expected to be catastrophic for environmental quality (IPCC 2014; McKinnon 2016; Santos 2017). According to the International Energy Agency (2016), transportation represents 30% of the EU's total GHG, of which road transport represented 72% in 2016. Despite relevant efforts made in other sectors of economy, pollution has increased for the transport sector, and its eventual reduction appears prohibitively expensive because the system and the global economy as a whole is highly dependent on fossil fuel consumption and traditional associated infrastructures (Santos 2017; Chatti et al. 2019). Therefore, both governments and transport companies have attempted to profit from some innovative solutions to dampen energy consumption, and thus reduce the environmental degradation associated with their activities.

Despite the key role that can be played by ICTs in reducing CO_2 emissions, few studies have investigated the links between ICTs, freight activity, and environment (Wang et al. 2015; Chatti 2020; Centobelli et al. 2020a, 2020b). Few empirical papers explicitly show how ICTs reduce pollution where interacting with freight transport. The existing literature is focused in general on the identification of green practices and new technologies employed by industrial and service companies (Wang et al. 2015), but fails to identify the most efficient new technologies that can significantly decrease the environmental damages (Centobelli et al. 2020a, 2020b; Chatti 2020). In addition, most studies have paid more attention to road freight transport, neglecting the responsibility of other transportation modes in increasing pollution (e.g. air, rail, and sea).

This study aims to enrich the existent literature by exploring how new technologies interact with freight transport to improve environmental quality with regard to carbon emissions reductions. The main contributions are presented as following. First, it aims to identify the most efficient technology that can dampen the negative impacts of freight transport activities (i.e. road, rail, inland, and air). Second, it sheds light on the importance of combining both new technologies and multimodality (i.e. road-rail) as an ambitious solution for reducing pollution. Third, it attempts to explicitly propose an empirical analysis that quantify the real effect of using new technologies in freight transportation on environment. Finally, it provides some practical policies in order to positively affect environmental quality for both developing and developed countries.

2. Literature review

Several papers have examined the question of environmental sustainability in relation to CO_2 emissions reductions. Some of them attempted to examine the links relating ICTs to environmental damages (Añón Higón et al. 2017; Park et al. 2018; Asongu et al. 2019), supply chain management and logistics (Cucchiella and Koh 2012; Nilsson and Sternberg 2017; Oláh et al. 2017; Molero et al. 2019; Centobelli et al. 2020a, 2020b), and freight transport (Giannopoulos 2004; Ozcan and Apergis 2018; Tob-Ogua et al. 2018; Centobelli et al. 2020a, 2020b; Chatti 2020).

To understand the first relationship, Añón Higón et al. (2017) used a panel set covering 142 countries between 1995 and 2010. The found that ICT can negatively affect environmental quality as a result of the increasing production of devices, ICT-related machines, and recycling of electronic waste. However, over the medium to long term, ICT can reduce carbon emissions by promoting smart cities, transportation networks, logistics network optimization, and energy consumption saving. They showed that several developed countries have succeeded in reaching the required level of ICT development whereby undesirable effects are reduced significantly.

Asongu (2018) examined the links relating ICTs, globalization, and carbon emissions using 44 African countries over the period 2000-2012, exploring whether ICTs positively interact with globalization to improve environmental sustainability. Using the GMM methodology, the results showed the capability of ICTs to reduce the undesirable impacts of globalization on environment. Similarly, Asongu et al. (2018) investigated the links relating ICTs to CO_2. They measured ICTs in terms of internet and mobile phones adoption, and pollution in terms of CO_2 emissions. The findings showed that ICTs cannot influence pollution when considering non-interactive estimations. Conversely, based on the interactive regressions, they found a positive effect on environmental damages with regard to the augmentation of CO_2 emissions per capita. However, mobile phone technologies positively affect environmental sustainability.

In the same context, Danish et al. (2018) attempted to clarify the relationship between ICTs and environmental quality through the interaction of ICTs with GDP and financial development. Using a set of panel models applied on emerging countries over the period 1990-2015, they found some interesting results: (i) ICTs, GDP and financial development positively affect CO_2 emissions; (ii) the interaction of ICT with GDP is able to decrease environmental damages; and (iii) the association of ICT and finance negatively affects environment. In terms of public policy, the authors suggested the application of green-ICT approach into the financial sector in order to decrease environmental damages. In the same context, Park et al. (2018) examined whether ICT, globalization (i.e. trade and financial development), and GDP affect environmental degradation using a sample of some European countries between 2001 and 2014. They found that ICT has a long-run relationship with pollution. However, while electricity use increases the level of pollution in European countries, GDP and financial development positively affect the environment. The results broadly show that European countries have not yet attained the required threshold for adopting green ICTs.

To understand the relationship between ICTs and freight transport, Chatti (2020) investigated whether ICT interacts with road freight transport to dampen the potential negative effects on the environment. Indeed, the adoption of fixed and mobile phones in transport activity can reduce CO_2 emissions more than internet use. These new technologies are able to decrease CO_2 emissions by 2.26% and 0.85%, respectively. However, using a set of control variables, the adoption of mobile phone technology in freight activity appears more appropriate in terms of pollution reduction than the use of telephone and internet. Indeed, ICTs can be considered a solution for reducing pollution, especially where interacting with road freight transport to increase energy efficiency (i.e. facilitating smart transport and software systems, and electronic marketplaces). Therefore, ICTs can also decrease energy consumption, and thus improve environmental driving practices.

Other works also attempted to identify various practical options in order to reduce pollution that is generated by transportation. Fuchs (2008) examined how ICTs affect environmental quality by discussing the role of telework in reducing pollution. Using ICTs for professional purposes traditionally conducted by people going to particular places *ipso facto* can reduce the need for travelling, and thus the negative environmental impacts of moving goods and people (Alakeson et al. 2003). Similar effects arise when people and businesses choose to avoid unnecessary travelling and use greener modes of transportation. Actually, ICTs facilitate social relationships by connecting both people and businesses. Some experts suggest the use of teleworking and teleconferencing as good options for reducing physical contacts, hence reducing CO_2 emissions.

Wang et al. (2015) investigated whether ICT contributes to decreasing CO_2 emissions generated by road freight transport. Based on some case studies covering three UK grocery retailers, they found that ICT improves environmental outcomes, and they proposed some ways to decrease emissions by reduced energy consumption. Firstly, transport companies can optimize logistics operations by adopting advanced ICTs to reduce environmental damages caused by road freight transport environmental outcomes, given that 6% of atmospheric pollution is mainly caused by road freight transport (McKinnon 2010). Several new applications (e-ticketing, smart transport, and reservations) are gaining popularity in this regard, helping companies better identify the most efficient combinations of networks with lower energy demand, thereby enhancing good practices for a more sustainable freight system (Agheli and Hashemi 2018; Centobelli et al. 2020a, 2020b; Tsakalidis et al. 2020).

In the same context, Tacken et al. (2013) provided some solutions to improve environmental performance in the German logistics service sector, including the promotion of some practices such as intermodality, logistics optimization, adaptability of vehicles, and fuel efficiency solutions. Santos (2017) recognized the application of short-term tax incentives and subsidizes, and long-term innovation to reduce GHG emissions from road transport. Llano et al. (2018) showed the importance of intermodality (road/rail) on environmental sustainability in Spain. Promoting intermodality in freight transport appears (among other options) to be a good solution for more efficient and sustainable transport systems. In the literature, we find also some other papers that attempted to examine the links between ICTs and supply chain management and logistics. Oláh et al. (2017) examined the links between the use of new technologies and the performance of logistic service providers (LSPs) in Hungary. The adoption of new technologies especially in logistic activities positively affects the profitability of companies. Centobelli et al. (2020a, 2020b) also highlighted the key role that can be played by green practices and ICTs in order to help companies acting in freight and logistics service. The use of innovative practices and technologies in addition to some supporting policies is able to reach sustainable development objectives.

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3. Methodology

3.1. Data

We examine whether information technology interacts with freight transportation to improve environmental quality through the reduction of carbon emissions. To reach this goal, we employ a strongly balanced panel data comprising 43 countries[1] between 2002 and 2014. The chosen economies and time frame are dictated by the availability of dataset. The dependent variable is defined in terms of carbon emissions derived from liquid energy. ICTs are indexed by the variables internet, mobile phones, and fixed telephone networks, as used by numerous previous researchers, including Asongu et al. (2019). We integrate also four control variables[2]. Table 1 defines all variables. Table 2 reports descriptive statistics. Table 3 presents correlations which may relate variables to each other. Here, it should be noted that the existence of multicollinearity issues is less significant when using interactive estimations (Brambor et al. 2006).

Table 4 shows the stationarity properties of all variables using Levin-Lin-Chu test (LLC 2002) and Im-Pesaran-Shin unit root test (IPS 2003). Despite the fact that LLC unit root test is considered less efficient for smaller samples, it takes into account the heterogeneity of sections. The main advantage of using IPS unit root test is related to its ability to perform in small samples by considering the heterogeneity between them, whereby it eliminates serial correlation.

The acceptance of the null hypothesis (H0) indicates that series are not stationary, whereas the alternative hypothesis confirms the stationarity of different series. To decide between the acceptance and the rejection of the null hypothesis, the p-value level can be compared with the threshold of 10%. Considering the empirical specification related to ICTs, road freight transport, and CO_2 emissions, the reported results confirm the stationarity of most variables except mobile phone and telephone adoption, which become stationary at the first difference. For the two other empirical specifications related to rail and inland freight transport, we find the same results in

[1] The 43 countries are: Armenia, Australia, Austria, Azerbaijan, Belgium, Bulgaria, Canada, China, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Mexico, Moldova, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Slovak Republic, Slovenia, South Korea, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States.

[2] We include four control variables in the first estimation (Table 5) related to the empirical links between ICTs, road freight transport and carbon emissions. For the other estimations (Table 6, 7 and 8), only three control variables are considered, such as population growth, regulation, and trade openness.

terms of stationarity. Concerning the empirical specification related to ICTs, air freight transport, and CO_2 emissions, most variables are stationary, except air freight transport, which becomes stationary only at the first difference.

Table 1. Variable definitions

Variables	Definitions	Sources
CO2liq	CO_2 emissions from liquid fuel consumption	WDI
INT	Internet users per 100 inhabitants	WDI
MOB	Mobile phone subscriptions per 100 inhabitants	WDI
TEL	Telephone landline subscriptions per 100 inhabitants	WDI
GDPg	Per capita GDP growth rate	WDI
POPg	Population growth rate	WDI
REG	Regulation quality	WDI
TO	Imports + exports of goods and services (% of GDP)	WDI
RdFT	Road freight transport in million ton-km	OECD
IFT	Inland freight transport (road/rail) in million ton-km	OECD
RFT	Rail freight transport in million ton-km	OECD
AFT	Air freight transport in million ton-km	OECD

Note: WDI = World Development Indicators

Table 2. Descriptive statistics

	Obs.	Mean	S.D.	Min.	Max.
CO2liq	559	164066.3	372406.3	817.741	2446414
INT	559	57.173	25.4099	1.537	98.16
MOB	559	97.680	32.846	1.192	172.178
TEL	559	38.883	15.498	2.083	74.616
GDPg	559	2.488	4.505	-14.559	32.997
POPg	559	0.417	0.803	-2.258	2.890
REG	559	1.017	0.667	-0.706	1.970
TO	559	91.524	51.458	20.685	392.804
RdFT	559	245501.8	759892.6	182	5953486
IFT	546	569113.4	1700150	660	1.26e+07
RFT	533	206012.6	604413	79	2946579
AFT	494	2979.86	6526.961	0	40617.74

Note: S.D. = Standard Deviation. Obs. = Observations

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Table 3. Correlation matrix

	CO2liq	INT	MOB	TEL	GDPg	POPg	REG	TO	RdFT
CO2liq	1								
INT	-0.0203 (0.6317)	1							
MOB	-0.1503*** (0.0004)	0.6385*** (0.0000)	1						
TEL	0.1605*** (0.0001)	0.5409*** (0.0000)	0.1942*** (0.0000)	1					
GDPg	-0.1192* (0.0048)	-0.4442* (0.0000)	-0.4057*** (0.0000)	-0.3415*** (0.0000)	1				
POPg	0.3143* (0.0000)	0.1572* (0.0000)	-0.0967** (0.0222)	0.1953*** (0.0000)	-0.1576*** (0.0002)	1			
REG	-0.0151 (0.7218)	0.7312* (0.0000)	0.4356*** (0.0000)	0.6650*** (0.0000)	-0.3886*** (0.0000)	0.1826*** (0.0000)	1		
TO	-0.5279 (0.0000)	0.2292* (0.0000)	0.3035* (0.0000)	0.0175 (0.6801)	0.0159 (0.7068)	-0.0098 (0.8179)	0.2133*** (0.0000)	1	
RdFT	0.9302* (0.0000)	-0.0595 (0.1604)	-0.1070** (0.0113)	-0.0234 (0.5813)	-0.0544 (0.1987)	0.2286*** (0.0000)	-0.0673 (0.1121)	-0.4549*** (0.0000)	1

Note: P-values in parentheses.
***Significant at 1%. ** Significant at 5%. * Significant at 10%.

Table 4. Unit root tests

	Levin-Lin-Chu test (LLC)		Im-Pesaran-Shin test (IPS)	
	Level	Diff (1)	Level	Diff (1)
Ln CO2liq	-8.6422*** (0.0000)		-5.1210*** (0.0000)	
INT	-8.8060*** (0.0000)		-3.0935*** (0.0010)	
MOB	-7.2098*** (0.0000)		0.7854 (0.7839)	-2.4949*** (0.0063)
TEL	-4.0727*** (0.0000)		3.0100 (0.9987)	-4.5465*** (0.0000)
GDPg	-10.0562*** (0.0000)		-7.0887*** (0.0000)	
POPg	-20.0123*** (0.0000)		-2.6722*** (0.0038)	
REG	-5.4250*** (0.0000)		-4.6755*** (0.0000)	
TO	-8.1422*** (0.0000)		-5.3435*** (0.0000)	
Ln RdFT	-10.2095*** (0.0000)		-3.3826*** (0.0004)	

Note: Estimated p-values are in parentheses.
*** Significant at 1%. ** Significant at 5%. *Significant at 10%.

3.2. Empirical strategy

In order to understand how ICTs influence environmental quality, we employ the two-step GMM methodology as proposed by Chatti (2020). The empirical choice is motivated by five reasons: (i) the number of groups (n=43) exceeds the time periods (t=13); (ii) the dependent variable (*lnCO2liq*) does not change, given that the coefficient of first lag variable is larger than 0.8; (iii) the empirical investigation considers an eventual endogeneity bias, using instruments and time-invariant omitted variables; (iv) "inherent biases in the difference estimator are corrected with the system estimator" (Asongu 2018); and (v) given that the empirical strategy is based on panel dataset, differences across groups are considered in estimations.

We use the extension developed by Roodman (2009)[3] in order to control the number of instruments, and consider any eventual dependence between sections[4] (Boateng et al. 2016). The used two-step GMM strategy is "represented by the following system of two equations in level and first difference (respectively), in which the error term takes a two-way error component form" (Asongu 2018).

$$lnCO2liq_{i,t} = \alpha_0 + \alpha_1 lnCO2liq_{i,t-r} + \alpha_2 lnFT_{i,t} + \alpha_3 ICT_{i,t} + \alpha_4 ln(ICT.FT)_{i,t} + \sum_{n=1}^{4} \delta_n W_{n,i,t-r} + \gamma_i + \mu_t + \varepsilon_{i,t}$$

$$lnCO2liq_{i,t} - lnCO2liq_{i,t-r} = \alpha_1\left(lnCO2liq_{i,t-r} - lnCO2liq_{i,t-2r}\right) + \alpha_2\left(lnFT_{i,t} - lnFT_{i,t-r}\right) + \alpha_3\left(ICT_{i,t} - ICT_{i,t-r}\right) + \alpha_4\left(lnICT.FT_{i,t} - lnICT.FT_{i,t-r}\right) + \sum_{n=1}^{4} \delta_n \left(W_{n,i,t-r} - W_{n,i,t-2r}\right) + (\mu_t - \mu_{t-r}) + \varepsilon_{i,t-r}$$

where $lnCO2liq_{i,t}$ represents carbon emissions for country *i* at year *t*, α_0 is the constant, $lnFT$ is the quantity of merchandise loaded by each transport mode, ICT is the communication

[3] The lagged levels developed by Arrelano and Bond (1991) cannot serve as "instruments for first differenced variables, particularly if the variables are close to a random walk" (Roodman 2009, p. 114). To tackle this issue, we used the Arrelano-Bover (1995) methodology, extending the Arrelano-Bond estimator to include a new assumption: "those first differences of instrument variables are uncorrelated with the fixed effects" (Roodman 2009, p. 86). Consequently, this consideration enables the "inclusion of more instruments", thereby improving estimates.
[4] Baltagi (2008).

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technology, $ln(ICT.FT)$ indicates the association between ICT and freight transportation by mode, W incorporates four independent variables, r equals one (indicating the coefficient of autoregression), μ_t is the time-specific constant, γ_i is the country effect, and $\varepsilon_{i,t}$ is the error term.

The dependent variable depends on a set of independent variables (i.e. *ICT*, *FT*, *POPg*, *GDPg*, *TO*, and *REG*). The main variables that can affect environmental quality have been highlighted by several studies (e.g. Omri et al. 2015). Therefore, freight transport is expected to be associated with negative environmental effects (Wang et al. 2015; Saidi and Hammami 2017; Chatti 2020). The most egregious of these for macroeconomic analysis are carbon emissions (although localized air pollution is also a major issue), GDP per capita and population growth, whereas regulation is expected to reduce pollution (Asongu et al. 2018).

4. Results and discussion

Two empirical specifications are considered in the estimations: without and with control variables (i.e. GDP per capita, population, regulation quality, and trade openness). Within each empirical specification, we consider three specifications in relation to road transportation. Moreover, each sub-specification is characterized in terms of different ICT technology. As used in several works, we utilize two tests to insure that the empirical strategy is appropriate: the test of AR(2) and the Hansen *J*-test. These tests indicate that the null hypothesis confirms the absence of correlation between instruments and error term, and the excluded instruments are not taken into account in the regressions. In addition, we show the Arrelano and Bond (1991) test, namely AR(2), "where the null hypothesis (H0) indicates that the differenced errors are auto-correlated, since the regression errors are not dependent and equally distributed" (Chatti 2020, p. 129). The AR(2) test is "not robust" and is "weakened by instruments", while the Hansen *J*-test is robust, but is also weakened by instruments. This latter is adopted to restrict the increase of instruments.[5]

Table 5 shows that ICTs positively affect CO_2 emissions in both empirical specifications. This result affirms earlier findings by Asongu et al. (2019) and Chatti (2020). According to Añón Higón et al. (2017) and Majeed (2018), ICTs can negatively affect environmental quality due to the

[5]To avoid the proliferation of instruments, the total instruments in chosen sub-empirical specifications should be lower than the number of groups.

increasing production of devices, ICT-related machines, and recycling of electronic waste. However, the interaction between ICTs and road freight transportation has a positive environmental effect, as confirmed by McKinnon (2010) and Wang et al. (2015). ICTs are able to reduce environmental damages generated by road freight activity.

According to the first specification, without a conditioning information set, a 10% increase in the interaction *MOB*RdFT* can decrease carbon emissions by 2.29%. Specifically, a 10% increase in the interaction *INT*RdFT* reduces environmental degradation by 1.41%. Moreover, the magnitude of -0.253 signifies that a 10% increase in the interaction *TEL*RdFT* will reduce pollution by 2.53%. It is worth mentioning that the interaction between telephone technology and road freight transport (*TEL*RdFT*) is more efficient in reducing CO_2 emissions than the other associations (*INT*RdFT* and *MOB*RdFT*). In addition, the results further show that road freight transportation causes increased CO_2 emissions. These results corroborate those presented by Saidi and Hammami (2017) who found a positive impact of road freight activity on environmental degradation.

When considering control variables, we find the same positive relationship between ICTs and carbon emissions. Moreover, the interactions *MOB*RdFT* and *TEL*RdFT* cause decreased pollution, and hence improved environmental sustainability. The coefficients of -0.203 and -0.263 mean that a 10% increase in *MOB*RdFT* and *TEL*RdFT* involves respectively around 2.03% and 2.63% decreased environmental damages. In addition, the variable *RdFT* positively affects (i.e. increases) carbon emissions. The magnitudes of 0.187 and 0.251 imply that a 10% increase *RdFT* will increase CO_2 emissions by 1.87% and 2.51%, respectively.

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Table 5. ICTs, road transportation, and carbon emissions

Variables	CO2liq					
	Road Freight Transportation (*RdFT*)					
	Without Conditioning Information			With Conditioning Information		
	MOB	INT	TEL	MOB	INT	TEL
Constant	0.860*** (0.000)	0.475** (0.032)	0.657*** (0.000)	0.741** (0.010)	0.335 (0.210)	0.679*** (0.003)
Ln CO2liq (-1)	1.017*** (0.000)	0.995*** (0.000)	1.006*** (0.000)	1.008*** (0.000)	0.998*** (0.000)	1.009*** (0.000)
Internet		0.002** (0.021)			0.002* (0.062)	
Mobile	0.002*** (0.005)			0.002** (0.017)		
Telephone			0.007*** (0.003)			0.006* (0.072)
Ln RdFT	0.204*** (0.000)	0.138* (0.051)	0.242*** (0.002)	0.187** (0.010)	0.124 (0.151)	0.251** (0.014)
Ln INT*RdFT		-0.141** (0.026)			-0.124 (0.131)	
Ln MOB*RdFT	-0.229*** (0.001)			-0.203** (0.011)		
Ln TEL*RdFT			-0.253*** (0.002)			-0.263** (0.017)
POP growth				0.035* (0.064)		0.011 (0.634)
Regulation				-0.016 (0.444)	-0.022 (0.195)	0.005 (0.686)
Trade				-0.00004 (0.841)	-0.00007 (0.684)	0.00003 (0.827)
GDP growth				0.001 (0.509)	0.004*** (0.001)	0.0002 (0.860)
AR(2) test	(0.477)	(0.495)	(0.123)	(0.338)	(0.289)	(0.113)
Hansen *J*-test	(0.355)	(0.255)	(0.362)	(0.353)	(0.623)	(0.345)
Instruments	39	39	39	39	39	39
Groups	43	43	43	43	43	43
Obs.	516	516	516	516	516	516

P-values in brackets.
*, **, *** significant at 10%, 5% and 1%, respectively

Table 6 reports the findings related to ICTs, inland freight transport, and carbon emissions. In this estimation, we use only three control variables: population growth, regulation, and trade openness. The results show that ICTs positively affect carbon emissions, similar to findings reported by Asongu et al. (2019), Chatti (2020) and Su et al. (2021). This is due essentially to their great dependency on electricity consumption in relation to the provision of equipment and devices, and

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the use of related infrastructures. The contribution of ICTs to global CO_2 emissions has been estimated to be 2% (Mingay 2007).

However, the results show that the interaction between ICTs and inland freight transport (road-rail) negatively affects carbon emissions. The coefficient of -0.236 shows that environmental degradation can be reduced by 2.36% if the interaction *MOB*IFT* improves by 10%. The coefficient of -0.127 indicates that a 10% increase in the interaction *INT*IFT* is able to decrease pollution by 1.27%. It is worth noting that the interaction *TEL*IFT* provides the most efficient and significant effect on environmental quality. Specifically, a 10% increase in the interaction *TEL*IFT* decreases carbon emissions by 3.02%. In the same context, Harris et al. (2014) and Llano et al. (2018) showed how the use of ICTs for multimodality[6] can decrease carbon emissions. Compared with road transport, the use of ICTs in inland freight transport (road-rail) appears less harmful to the environment.

With the inclusion of control variables, the mobile phones and telephone technologies seem to positively affect carbon emissions. The coefficients of 0.227 and 0.294 show that a 10% increase in *IFT* will increase environmental degradation by 2.27% and 2.94%, respectively. However, the interaction *MOB*IFT* positively affects environmental sustainability. The coefficient of -0.239 indicates that a 10% increase in the association *MOB*IFT* will result in a decrease in CO_2 emissions of around 2.39%. In addition, the interaction *TEL*IFT* shows the same positive and significant effect on environmental quality with regard to pollution reductions. More specifically, a 10% increase in *TEL*IFT* implies a 2.67% decrease in the pollution level. The results reinforce the association between multimodality and ICTs to facilitate data exchange and real-time visibility (Harris et al. 2014).

[6] Multimodality is defined as transportation activity using at least two modes of transport (e.g. road-rail, road-sea, etc.). Intermodality can be considered as a particular type of multimodality which utilizes the same loading unit, such as a shipping container.

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Table 6. ICTs, inland transportation, and carbon emissions

Variables	**CO2liq**					
	Inland Freight Transportation (IFT)					
	Without Conditioning Information			With Conditioning Information		
	MOB	INT	TEL	MOB	INT	TEL
Constant	0.913*** (0.000)	0.427** (0.020)	0.624** (0.030)	0.919*** (0.000)	0.602 (0.217)	0.612** (0.022)
Ln CO2liq (-1)	0.997*** (0.000)	0.994*** (0.000)	0.962*** (0.000)	1.000*** (0.000)	0.979*** (0.000)	0.971*** (0.000)
Internet		0.001* (0.096)			0.003 (0.141)	
Mobile	0.002*** (0.004)			0.002** (0.021)		
Telephone			0.010** (0.024)			0.008* (0.076)
Ln IFT	0.230*** (0.000)	0.127* (0.087)	0.341** (0.023)	0.227*** (0.000)	0.201 (0.251)	0.294* (0.057)
Ln INT*IFT		-0.127** (0.023)			-0.187 (0.169)	
Ln MOB*IFT	-0.236*** (0.001)			-0.239*** (0.002)		
Ln TEL*IFT			-0.302** (0.039)			-0.267* (0.063)
POP growth				0.020 (0.341)	0.034 (0.140)	0.026 (0.311)
Regulation				-0.002 (0.916)	-0.017 (0.518)	-0.015 (0.460)
Trade				0.0001 (0.700)	-0.00005 (0.839)	-0.0001 (0.606)
AR(2) test	(0.471)	(0.488)	(0.321)	(0.484)	(0.472)	(0.336)
Hansen *J*-test	(0.327)	(0.308)	(0.537)	(0.530)	(0.270)	(0.482)
Instruments	40	40	40	39	39	39
Groups	42	42	42	42	42	42
Obs.	504	504	504	504	504	504

P-values in brackets.
*, **, *** significant at 10%, 5% and 1%, respectively

Table 7 reports the findings in relation with ICTs, air freight transport, and CO_2 emissions. Based on the first empirical specification without control variables, air freight transport positively affects (i.e. increases) environmental damage. The magnitudes of 0.157, 0.107 and 0.198 imply that a 10% increase in air freight transport may increase carbon emissions by 1.57%, 1.07%, and 1.98%, respectively. However, the interactions *INT*AFT*, *MOB*AFT* and *TEL*AFT* seem to have negative effects on carbon emissions, which indicates that increasing ICT adoption in air freight transportation will accelerate its positive impact on environmental quality.

Table 7. ICTs, air transportation, and carbon emissions

Variables	**CO2liq**					
	Air Freight Transportation (AFT)					
	Without Conditioning Information			With Conditioning Information		
	MOB	INT	TEL	MOB	INT	TEL
Constant	0.588** (0.034)	0.335** (0.035)	0.546* (0.075)	0.608** (0.031)	0.383* (0.075)	0.636 (0.231)
Ln CO2liq (-1)	0.990*** (0.000)	0.993*** (0.000)	0.993*** (0.000)	0.990*** (0.000)	1.003*** (0.000)	0.999*** (0.000)
Internet		0.001 (0.182)			0.003* (0.068)	
Mobile	0.001 (0.102)			0.001 (0.179)		
Telephone			0.005 (0.142)			0.006 (0.369)
Ln AFT	0.157** (0.041)	0.107** (0.069)	0.198* (0.093)	0.163* (0.054)	0.160* (0.071)	0.246 (0.289)
Ln INT*AFT		-0.104* (0.079)			-0.163* (0.082)	
Ln MOB*AFT	-0.153** (0.042)			-0.158** (0.054)		
Ln TEL*AFT			-0.197* (0.097)			-0.250 (0.288)
POP growth				0.016 (0.279)	0.029* (0.051)	0.023 (0.259)
Regulation				-0.016 (0.424)	-0.018 (0.430)	0.006 (0.852)
Trade				0.00001 (0.935)	0.00003 (0.847)	0.00009 (0.734)
AR(2) test	(0.463)	(0.429)	(0.734)	(0.432)	(0.266)	(0.682)
Hansen *J*-test	(0.416)	(0.344)	(0.242)	(0.357)	(0.351)	(0.188)
Instruments	34	34	34	35	35	35
Groups	38	38	38	38	38	38
Obs.	456	456	456	456	456	456

P-values in brackets.
*, **, *** significant at 10%, 5% and 1%, respectively

Considering the second specification, it appears that air freight transportation positively increases carbon emissions. A 10% increase in air freight activity may increase carbon dioxide emissions by

1.63% and 1.60%, respectively. This suggests that increasing air freight transport undermines environmental sustainability. However, the adoption of ICTs in air transportation can improve environmental quality. In terms of elasticities, the magnitudes of -0.158 and -0.163 note that a 10% increase in *MOB*AFT* and *INT*AFT* leads respectively to 1.58% and 1.63% decreased pollution. These findings are largely supported by several authors who underlined the importance of using internet and mobile phone technologies to reduce CO_2 emissions. Using efficient infrastructure networks, ICTs can reduce the need for transportation (see Gutierrez et al., 2009). The simple association of mobile phones with internet technology reduces the need for physical contacts, and thus decreases urban costs. In addition, the adoption of internet applications can be useful for companies' competitiveness, particularly in the air transport sector (Buhalis 2004; Wang et al. 2011; Agheli and Hashemi 2018).

Table 8 presents the findings related to ICTs, rail freight transport, and CO_2 emissions. The results broadly show the positive impact of *RFT* on carbon emissions, confirming its negative impact on the environment, reaffirming earlier studies (e.g. Asongu 2019; Chatti 2020). Specifically, the magnitudes of 0.157, 0.117, and 0.207 show that a 10% increase in rail freight transport may increase pollution by 1.57%, 1.17%, and 2.07%, respectively. However, the interaction between ICTs and rail freight transport seems to have a positive impact on environmental sustainability. Firstly, the coefficient of -0.111 reports that a 10% increase in *INT*RFT* will decrease environmental damages by 1.11%. Secondly, the magnitude of -0.155 indicates that a 10% increase in the interaction *MOB*RFT* will reduce carbon emissions by 1.55%. Thirdly, the magnitude of -0.194 indicates that a 10% increase in the interaction *TEL*RFT* will improve environmental quality by 1.94%. Moreover, the findings further suggest that the association *TEL*RFT* is more efficient in terms of reducing environmental degradation than the use of internet and mobile phone technologies.

Relative to the second specification, the findings show that rail freight transport positively affects pollution. Specifically, the coefficients of 0.181 and 0.198 imply that a 10% increase in *RFT* is able to reduce emissions by 1.81% and 1.98% (respectively). However, the adoption of new technology in *RFT* can improve the environment, with the consideration of CO_2 emissions reductions. The magnitudes of -0.162 and -0.191 show that the environmental quality will be increased by 1.62% and 1.91% (respectively) if the interactions *MOB*RFT* and *TEL*RFT* improve by 10%. Moreover, it is worth noting that the combination *INT*RFT* does not affect the environment. The findings also illustrate that the adoption of telephone technology in *RFT* is more efficient in reducing carbon emissions than utilizing internet and mobile phone technologies. The use of new technologies is clearly of importance in the management of organizations, and is seen as a key factor of the integration of supply chain and companies' competitiveness (Cepolina and Ghiara 2013; Molero et al. 2019).

Table 8. ICTs, rail transportation, and carbon emissions

Variables	**CO2liq**					
	Rail Freight Transportation (RFT)					
	Without Conditioning Information			With Conditioning Information		
	MOB	INT	TEL	MOB	INT	TEL
Constant	0.591*** (0.001)	0.324 (0.106)	0.454 (0.127)	0.708** (0.049)	0.328 (0.619)	0.627* (0.061)
Ln CO2liq (-1)	0.994*** (0.000)	0.994*** (0.000)	0.986*** (0.000)	0.969*** (0.000)	0.991*** (0.000)	0.975*** (0.000)
Internet		0.001* (0.064)			0.002 (0.248)	
Mobile	0.001** (0.025)			0.001 (0.115)		
Telephone			0.006*** (0.000)			0.006*** (0.001)
Ln RFT	0.157*** (0.001)	0.117** (0.018)	0.207*** (0.000)	0.181** (0.03)	0.188 (0.202)	0.198*** (0.001)
Ln INT*RFT		-0.111** (0.021)			-0.164 (0.238)	
Ln MOB*RFT	-0.155*** (0.002)			-0.162** (0.010)		
Ln TEL*RFT			-0.194*** (0.003)			-0.191*** (0.002)
POP growth				0.062** (0.027)	0.035 (0.239)	0.034 (0.329)
Regulation				-0.008 (0.602)	-0.011 (0.704)	-0.012 (0.697)
Trade				-0.0001 (0.671)	0.0001 (0.724)	-0.0002 (0.541)
AR(2) test	(0.456)	(0.485)	(0.282)	(0.474)	(0.494)	(0.296)
Hansen *J*-test	(0.433)	(0.237)	(0.458)	(0.411)	(0.311)	(0.309)
Instruments	34	34	34	39	39	39
Groups	41	41	41	41	41	41
Obs.	492	492	492	492	492	492

P-values in brackets.
*, **, *** significant at 10%, 5% and 1%, respectively

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5. Conclusion and policy implications

This paper investigated whether the interaction between ICTs and freight transport can influence CO_2 emissions in 43 countries between 2002 and 2014. ICTs are measured in terms of internet, mobile phones, and telephone adoption, while freight transport is approximated in terms of road, rail, inland, and air freight transport. Using GMM approach, the results suggest some interesting findings: (i) the only use of ICTs and freight transport increase CO_2 emissions; (ii) the interaction between ICTs and freight transportation can improve environmental quality with regard to CO_2 emissions reduction; (iii) the interaction of telephone and mobile phone technologies with road, rail, and inland freight activities are more efficient in damping environmental degradation than adopting internet technology; (iv) the interaction between telephone and multimodality (i.e. road-rail) can significantly accelerate environmental quality; and (v) the use of internet is the most efficient technology in reducing CO_2 emissions where interacting with air freight transport.

In terms of policy implications, the results showed the important role that can be played by ICTs in order to dampen the costs and constraints generated by freight transport activity, which is an egregious cause of pollution. Indeed, a 10% increase in the association between ICTs and freight transport will reduce environmental degradation by between 1.27% and 3.02%. Therefore, both policy makers and transport companies could fully profit from the implementation of new ICT solutions for logistics and transportation. Actually, some innovative ICTs integrate big data, artificial intelligence, and internet of things. These breakthrough technologies are crucial to facilitate management, planning, and supply chain applications during the movement of merchandise (Molero et al. 2019). The findings also suggest the importance of adopting ICTs in multimodal transport in order to accelerate environmental sustainability. Specifically, the simple interaction between telephone adoption and inland freight transport can reduce carbon emissions by between 2.39% and 3.02%.

Finally, this empirical research is the first to explicitly identify the capability of ICTs in reducing environmental degradation when interacting with various modes of transport. This paper also highlights the necessity of applying the appropriate new technology, dependent on each specific mode of transport (i.e. the use of internet for air freight transport). For future research, we plan to consider the heterogeneity across developing and developed countries as proposed by Majeed

(2018). Indeed, the interaction between ICTs and freight transport could have different effects on environmental sustainability, dependent on the level of development of each group. Moreover, it would be interesting to examine how some new technologies interact with passenger transport activities to reduce pollution, taking into account other pollution indicators (e.g. CO_2 intensity, CO_2 emissions, etc.).

Conflict of interest

The author declares that there is no conflict of interest.

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