




“Information and communication technologies, road freight transport, and environmental sustainability”

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INFORMATION AND COMMUNICATION TECHNOLOGIES, ROAD FREIGHT TRANSPORT, AND ENVIRONMENTAL SUSTAINABILITY

Abstract

Despite progress in reducing air pollutants in several countries, freight transport continues to have undesirable effects on environmental quality, human health, and the economy. Road freight transport, in particular, is associated with various negative externalities, including environmental and health damages, and the overexploitation of non-renewable natural resources. This paper investigates how ICTs interact with road freight transport to affect environmental quality regarding reducing CO₂ emissions. The empirical strategy is focused on the yearly dataset from 2002 to 2014 in 43 countries. Using the two-step GMM techniques, the findings suggest that ICTs can decrease road freight transport's negative impacts on environmental sustainability. Besides, the interactions of mobile phone and fixed telephone technologies with road freight transport are more efficient in reducing pollution than using internet networks. This paper underlines the importance of using ICTs to dampen road freight transport's negative effects on environmental sustainability.

Keywords

ICT, transport, CO₂ emissions, environmental quality, GMM

JEL Classification

O33, R41, Q53, Q56, C13

INTRODUCTION

Transportation is a major contributor to global CO₂ emissions, one of the main factors in global warming. If the average global temperature exceeds 2° C's safety level, then catastrophic impacts on environmental sustainability could ensue (IPCC, 2014). Transport contributed 23% of global carbon emissions from energy consumption, whereas road transport contributed 20% in 2014 (International Energy Agency, 2016). For example, road transport represents almost 92% of total CO₂ in UK, and 6% of total CO₂ emissions (Piecyk & McKinnon, 2010). Since the ratification of the Kyoto Protocol on Climate Change, CO₂ emissions have increased, especially in some regions such as China and India, while decreasing in certain areas, such as Europe (Olivier & Muntean, 2014). Despite significant decreases in many other sectors of the economy, CO₂ emissions have continued to increase in the transportation sector, and reducing environmental damage caused by transport seems to be more costly than in other sectors because it heavily depends on fossil fuels and traditional supporting infrastructure (i.e., diesel and petrol used in combustion engines). Consequently, all involved actors and users of road transport services have attempted to integrate some innovative solutions and clean technologies to reduce energy consumption by transportation and environmental pollution.

For reducing CO₂ emissions and associated costs of their road freight transport networks, many companies in recent years have adopted

rapid advances in ICTs and their useful applications for road transport. These innovative applications can include on-vehicle systems (i.e., telematics and radio frequency identification) and in-house systems (e.g., computerized vehicle scheduling system). In the same context, the adoption of useful internet applications (e.g., electronic marketplaces, e-tickets, software systems, smart transport systems, and electronic reservation) is becoming very popular nowadays. These can also help companies identify the best combinations of routes that consume less energy and stimulate good driving practices to improve environmental quality.

This study aims to examine how ICTs can diminish the potential negative effect of road freight transport on the environment and identify the most efficient ICT technologies (internet, telephone, and mobile phones) that can be used to reduce CO₂ emissions. The main contributions are twofold: theoretically speaking, this study aims to develop the knowledge about the role played by the interaction of ICTs with road freight transport in reducing pollution, and from an empirical point of view, this study proposes some practical options to accomplish environmental benefits using some specific ICTs devices.

1. LITERATURE REVIEW

Although there is an important role to be played by ICTs in increasing cost efficiency and reducing pollution, very few studies have attempted to explore potentials in CO₂ reduction by adopting ICT for road freight transport (Wang, Potter, Naim, & Beevor, 2011; Wang, Rodrigues, & Evans, 2015; Agheli & Hashemi, 2018). This gap was noted by Perego, Perotti, and Mangiaracina (2011) in their study identifying relationships between using ICTs for logistics and freight transport. Considering more than 40 papers, they found only the paper of Button, Doyle, and Stough (2001) that highlighted the impact of using ICTs in the context of freight transport to reduce environmental degradation. To our knowledge, few articles have been using an empirical methodology to demonstrate the impacts of ICTs in reducing environmental damages of road freight transport.

Some studies have indeed explored the question of environment concerning ICTs (Park, Meng, & Baloch, 2018; Danish Khan, Baloch, Saud, & Fatima, 2018; Asongu, Nwachukwu, & Pyke, 2019), supply chains (Tacken, Sanchez-Rodrigues, & Mason, 2013), and road transport (Button et al., 2001; Giannopoulos, 2004; McKinnon, 2011; Mahmoudzadeh & Fathabadi, 2011; Wang et al., 2015; Li & Yu, 2017; Santos, 2017).

Regarding the first relation, Añón Higón, Gholami, and Shirazi (2017) studied the relationship between ICT and environmental pollution. They mentioned that the ICT turning level is located

above the mean value for developing countries, but the opposite scheme is true for developed countries. These results mentioned that several developed countries have already reached a level of ICT development whereby pollution is decreased. Asongu, Le Roux, and Biekpe (2018) examined how ICTs can influence Africa's environmental sustainability using a set of 42 countries between 2000 and 2012. They showed a positive relationship between ICTs and CO₂ emissions due to energy consumption. Asongu (2018) investigated how ICTs interact with globalization to affect CO₂ emissions using panel data of 44 countries from 2000 to 2012. He showed that ICTs could decrease the negative effects of globalization by reducing environmental damage.

Danish et al. (2018) also investigated how ICTs, per capita GDP growth, and financial expansion influence environmental quality. They considered two different associations: between ICTs and GDP per capita, and between ICTs and financial development. They employed an empirical strategy using a set of econometric techniques over the period 1990–2015. They concluded that ICTs, financial development, and per capita GDP growth positively affect CO₂ emissions. When ICTs are associated with financial development, this may increase environmental damage. The only positive effect on environmental sustainability is the interaction between ICT and per capita GDP growth. Moreover, Park et al. (2018) investigated the potential impacts of new technologies on the pollution reduction for 23 EU countries between 2001 and 2014, confirming that ICTs may positively in-

crease carbon emissions in the long run. Similarly, the usage of electricity consumption has the same positive effect. However, per capita GDP growth, trade, and financial expansion negatively affect carbon emissions. In terms of policy implications, they recommended that the EU countries encourage ecological ICT devices and adopt the new inventions on the internet to decrease environmental degradation.

To understand the empirical relationship between transportation and carbon emissions, Saidi and Hammami (2017) considered 75 countries between 2000 and 2014 using three sets of countries categorized according to income level. They employed dynamic models in a simultaneous system of equations estimated through GMM procedure, consequently detecting a unique directional causality going from freight transport to CO₂ emissions for the high-income panel. Moreover, they found a negative effect of road freight transport on low- and middle-income countries' environmental degradation. Li and Yu (2017) investigated how smartphones could interact with road freight transport to reduce environmental damage. For this, they used some case studies to evaluate their applications in China. By conducting some interviews and using other data collection techniques, they found that freight applications can help identify the adequate trucks, achieve the delivery process, and improve traffic management. Therefore, this can improve efficiency and decrease CO₂ emissions from fuel consumption.

Other studies underscore the imperative necessity to manage logistics operations positively influencing environmental quality, especially given that 6% of net carbon emissions are from road freight transport (McKinnon, 2010). The rapid growth in the amount of energy consumption for road freight transport surpasses the total quantity of energy used by cars and buses (Wang et al., 2015). Therefore, some technical solutions are proposed by several studies to reduce pollution coming from road freight networks. In the same context, the European Commission investigated how ICT can reduce energy consumption

in road transport and suggested some solutions to the importance of adopting eco-solutions and tools for improved traffic management (Klunder et al., 2009). Tacken et al. (2013) identified some practical options to dampen CO₂ emissions generated by road freight transport in the German logistics service sector in terms of intermodality, logistics network optimization, vehicle adaptability, and reduction of fuel solutions. Though these advances have improved the knowledge about the important role of ICT in decreasing pollution (Wang et al., 2015), the existing literature fails to provide a comprehensive idea concerning ICT's impact on road freight transport on environmental sustainability.

2. METHODS

2.1. Data

This paper exploits a panel dataset extracted from the World Bank (WDI, 2019) and OECD (2019) over 2002–2014. The selected countries and related timeframe are conditioned by data availability, especially CO₂ emissions from liquid fuel consumption¹, including 43 countries². The dependent variable is CO₂ emissions; its negative sign implies an improvement in environmental quality. Internet, mobile phone, and telephone adoption are employed as proxies to measure ICTs (Tony & Kwan, 2015; Tchamyou, 2016; Asongu, 2018; Asongu et al., 2018, 2019). Internet, mobile phone, and telephone (subscription) penetration are measured per 100 inhabitants as ICT variables. Besides, four control variables are taken into account: per capita GDP growth, trade development, regulation quality, and population growth. Table 1 indicates the full variable definitions and related data sources. Table 2 shows descriptive data. Table 3 identifies the correlations that can exist between all variables used in the empirical investigation. According to Brambor, Clark, and Golder (2006), the existence of multicollinearity issues is considered irrelevant in interactive regressions.

1 It is worth noting that there is no available data for the variable CO₂ emissions from liquid fuel consumption from 2015 till now. Consequently, the selected data is limited to the period between 2002 and 2014. However, this limitation does not affect the quality of estimations and results.

2 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 the United States.

Table 1. Variable definitions

Variables	Measurements	Source
CO ₂ emissions	Carbon emissions derived from liquid fuel consumption	World Bank (2019)
Internet	Internet users	World Bank (2019)
Mobile phones	Mobile phones access by 100 inhabitants	World Bank (2019)
Telephone	Telephone landline access by 100 inhabitants	World Bank (2019)
Per capita GDP growth	Per capita GDP growth (annual %)	World Bank (2019)
Population growth	Population growth rate (annual %)	World Bank (2019)
Regulation quality	Regulation quality (estimate)	World Bank (2019)
Trade openness	Share of total importations and exportations in GDP	World Bank (2019)
Freight transport	Volume of freight transported by road in ton-kilometers (million)	OECD (2019)

Table 2. Summary statistics (2002–2014)

	Obs.	Mean	S.D.	Minimum	Maximum
CO ₂ emissions	559	164066.3	372406.3	817.741	2446414
Internet	559	57.173	25.4099	1.537	98.16
Mobile phones	559	97.680	32.846	1.192	172.178
Telephone	559	38.883	15.498	2.083	74.616
Per capita GDP growth	559	2.488	4.505	-14.559	32.997
Population growth	559	0.417	0.803	-2.258	2.890
Regulation quality	559	1.017	0.667	-0.706	1.970
Trade openness	559	91.524	51.458	20.685	392.804
Freight transport	559	245501.8	759892.6	182	5953486

Table 3. Correlation matrix

	CO ₂	INT	MOB	TEL	GDPg	POPg	REG	TO	FT
CO ₂	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	
FT	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: The estimated p-values are in brackets. *** Significant at 1%. ** Significant at 5%. * Significant at 10%.

2.2. Empirical strategy

To investigate how ICTs interact with road freight transport to influence environmental quality, a two-step GMM empirical strategy can be adopted. This choice is due to five main reasons as cited by Asongu (2018): (1) the set of groups ($n = 43$) exceeds the number of years ($t = 13$) in every cor-

responding group; (2) the variable of interest does not change, since its correlation coefficient with its first lag variable exceeds the level of 0.8; (3) the estimation strategy accounts for such a possible endogeneity bias through a process of instrumentation and time-invariant omitted variable; (4) inherent biases in the difference estimator are corrected with the system estimator (Asongu, 2018, p.

9353); (5) since the GMM approach is focused on panel data, disparities between countries are considered in regressions.

The Arellano and Bover (1995) extension developed by Roodman (2009)³ is used since it can easily control the increase of instruments, and thus consider the dependence that can exist between sections⁴ (Boateng, Asongu, Akamavi, & Tchamyou, 2016). The standard system GMM is represented by the following equations in level and first difference (respectively), in which the error term takes a two-way error component form:

$$CO2_{i,t} = \alpha_0 + \alpha_1 CO2_{i,t-r} + \alpha_2 FT_{i,t} + \alpha_3 ICT_{i,t} + \alpha_4 (ICT \cdot FT) + \sum_{n=1}^4 \delta_n W_{n,i,t-r} + \gamma_i + \mu_t + \varepsilon_{i,t}, \tag{1}$$

$$CO2_{i,t} - CO2_{i,t-r} = \alpha_1 (CO2_{i,t-r} - CO2_{i,t-2r}) + \alpha_2 (FT_{i,t} - FT_{i,t-r}) + \alpha_3 (ICT_{i,t} - ICT_{i,t-r}) + \alpha_4 (ICT \cdot FT_{i,t} - ICT \cdot FT_{i,t-r}) + \sum_{n=1}^4 \delta_n (W_{n,i,t-r} - W_{n,i,t-2r}) + (\mu_t - \mu_{t-r}) + \varepsilon_{i,t-r}, \tag{2}$$

where $CO2_{i,t}$ represents carbon emissions from liquid fuel consumption for country i at year t , α_0 represents the constant, FT indicates road freight transport, ICT considers internet, mobile phones, and telephone penetration, $ICT \cdot FT$ is a combination relating ICT variable and road freight transport, W integrates four control variables (population growth, per capita GDP growth, trade openness, and regulation quality), r takes 1 for the empirical specification and indicates the coefficient of autoregression, μ_t is the time-specific constant, γ_i indicates the country-specific effect, and $\varepsilon_{i,t}$ designates the error term.

The variability of the dependent variable is affected by ICT , road freight transport (FT), population growth ($POPg$), per capita GDP growth ($GDPg$), trade openness (TO), and regulation quality (REG). The principal factors that have some influence on the environmental degradation are reported in several studies (Halicioglu, 2009; Lee, 2013; Omri, Daly, Rault, & Chaibi, 2015; Chatti, Ben Soltane, & Abalala, 2019). Therefore, road freight transport and energy consumption are expected to have negative environmental effects (Saidi & Hammami, 2017). These variables are considered to be among the main causes of carbon emissions, in line with expectations regarding per capita GDP growth and population growth (Zhang & Lin, 2012), and they thus negatively affect environmental quality, while regulation quality is expected to positively affect the environmental quality (Asongu, 2018; Asongu et al., 2018).

3. RESULTS AND DISCUSSION

Table 4 shows the main findings. It considers two different specifications: the first one is without control variables, while the second contains four control variables. In each specification, three subsets of specifications related to road freight transport are presented. Besides, each sub-empirical specification contains three different measures of ICTs (i.e., mobile phone, internet, and telephone). Two tests are exploited to ensure that the GMM procedure is appropriate: the "test of overidentifying restriction" and the "test of endogeneity/exogeneity". The Hansen J -test outcomes appear in Table 4, in which $H0$ allows us to confirm that the instruments are not correlated with the error term, and the excluded instruments are not considered in the estimation.

This study also reports the Arellano and Bond (1991) test, namely AR(2), where the null hypothesis indicates that the differenced errors are auto-correlated since the regression errors are not dependent and equally distributed. Albeit the Sargan test is not robust, this corresponding test

3 The lagged levels in the Arellano-Bond estimator "are weak instruments for transformed variables, particularly if the variables are close to a random walk" (Roodman, 2009, p. 114). To avoid this potential weakness, the Arellano-Bover (1995) procedure is used. This estimator extends the Arellano-Bond estimator by adding a new assumption: "those first differences of instrument variables are uncorrelated with the fixed effect" (Roodman, 2009, p. 86). As a result, this extension allows the inclusion of more instruments, which improves the quality of estimation.

4 See Baltagi (2008) for more details.

Table 4. ICTs, road freight transport, and environmental sustainability

Variables	Carbon emissions derived from liquid fuel consumption					
	Road freight transport					
	Without control variables			With control variables		
	Mobile	Internet	Telephone	Mobile	Internet	Telephone
Constant	0.367** (0.044)	0.231* (0.068)	0.643* (0.052)	-0.316 (0.643)	-0.498 (0.432)	0.472* (0.052)
Ln CO ₂ (-1)	0.980*** (0.000)	0.986*** (0.000)	0.933*** (0.000)	0.977*** (0.000)	0.964*** (0.000)	0.953*** (0.000)
INT		0.0008 (0.354)			0.002 (0.141)	
MOB	0.0002 (0.662)			0.002*** (0.008)		
TEL			0.008** (0.012)			0.005* (0.072)
Ln FT	0.104** (0.036)	0.088** (0.041)	0.275** (0.016)	0.167** (0.026)	0.108 (0.100)	0.171** (0.045)
Ln INTxFT		-0.074* (0.058)			-0.091* (0.081)	
Ln MOBxFT	-0.085* (0.074)			-0.159*** (0.008)		
Ln TELxFT			-0.226** (0.046)			-0.141* (0.061)
GDPg				0.007*** (0.002)	0.005*** (0.000)	0.004*** (0.004)
POPg				0.011 (0.597)	0.014 (0.519)	0.001 (0.915)
REG				-0.073 (0.321)	-0.082 (0.282)	0.002 (0.930)
TO				-0.0005 (0.602)	-0.0006 (0.520)	-0.0003 (0.298)
AR(2) test	(0.442)	(0.452)	(0.314)	(0.209)	(0.217)	(0.229)
Hansen <i>J</i> -test	(0.478)	(0.341)	(0.542)	(0.553)	(0.481)	(0.514)
Number of instruments	40	40	40	39	39	40
Number of countries	43	43	43	43	43	43
Observations	516	516	516	516	516	516

Note: The estimated *p*-values in brackets. *** Significant at 1%. ** Significant at 5%. * Significant at 10%.

is not negatively affected by instruments, contrary to the Hansen test. To address this conflict, the Hansen test can be used for controlling the increase of instruments.⁵ The results of the Hansen *J*-test and AR(2) are shown in Table 4. The first test approves the acceptance of *H*₀, which means that the instruments are suitable, while the AR(2) test illustrates no autocorrelation evidence.

The findings broadly show the capability of ICTs in reducing the costs and constraints associated with freight transport using road transport networks, thereby decreasing CO₂ emissions and associated environmental degradation. This impor-

tant result is confirmed in most empirical studies (Baumgartner et al., 2008; Wang et al., 2015). More precisely, it appears that the interaction between ICTs (e.g., internet, mobile phone, and telephone penetration) and road freight transport has significant negative effects on CO₂ emissions, and therefore positive effects on environmental sustainability. Besides, relative to the specifications without control variables, the association of telephone penetration with road freight transport ($TEL \cdot FT$) seems to be more efficient in reducing CO₂ emissions than the internet and mobile phone penetration. The magnitude of -0.226 means that a 10% improvement in $TEL \cdot FT$ may

5 It is possible to avoid the proliferation of instruments when they do not exceed the number of groups in chosen sub-empirical specifications.

reduce CO₂ emissions by 2.26%. However, according to the empirical specification with control variables, the interaction between mobile phones and road freight transport ($MOB \cdot FT$) becomes the most efficient in reducing environmental damage. In terms of elasticities, the coefficient of 0.159 means that if $MOB \cdot FT$ improves by 10%, then CO₂ emissions decrease by 1.59%.

The findings also illustrate that road freight transport positively affects environmental degradation in most empirical specifications. In terms of elasticities, the coefficients of 0.104, 0.088, and 0.275 indicate that if the road freight transport activity increases by 10%, then CO₂ emissions increase correspondingly by 1.04%, 0.88%, and 2.75%. These results are reported by Saidi and Hammami (2017) who found the same negative impacts of freight transport on carbon emissions. Moreover, per capita GDP growth positively and significantly affects environmental degradation. The same result was found by several studies (Zhang & Lin, 2012; Saidi & Hammami, 2017).

CONCLUSION

This study's main goal is to investigate how ICTs interact with road freight transport to reduce carbon emissions in 43 countries over the period 2002–2014. The chosen period is conditioned by data availability, especially for the dependent variable (i.e., CO₂ emissions from liquid fuel consumption). The dataset is extracted from the World Development Indicators (World Bank). It is worth noting that this limitation does not affect the quality of estimates. The findings provide significant results concerning the impact of using ICTs in road freight transport on environmental sustainability. Although ICTs can play an important role in decreasing road transport's potential negative effect on environmental quality, few research contributions have been made. Using the two-step GMM techniques, the findings mainly demonstrate the ability of ICTs in decreasing potentially negative environmental impacts of road freight transport (i.e., reducing carbon emissions). The negative relationships between the use of ICTs (i.e., telephone, internet, and mobile phones) in road freight transport and CO₂ emissions attest to those technologies' capability in decreasing the costs and constraints related to the freight transport activity.

For both specifications, the impact of using ICTs in road freight transport on environmental quality was positive, regarding the reduction of CO₂ emissions. Indeed, a negative and significant impact was estimated for the interaction ($TEL \cdot FT$), where a 10% increase in $TEL \cdot FT$ may decrease CO₂ emissions by 2.26%. Moreover, for the interactions ($MOB \cdot FT$) and ($INT \cdot FT$), a 10% increase in $MOB \cdot FT$ and $INT \cdot FT$ may reduce carbon emissions by 0.85% and 0.74%, respectively. Thus, we conclude that the interaction ($TEL \cdot FT$) can decrease CO₂ emissions more efficiently than the other interactions, ($MOB \cdot FT$) and ($INT \cdot FT$). However, when considering the empirical specification with a control set of variables, it appears that the association ($MOB \cdot FT$) becomes the most efficient, leading to an increase in environmental quality. A 10% increase in $MOB \cdot FT$ may reduce CO₂ emissions by 1.59%.

Finally, this paper is the first to explicitly propose an empirical analysis to identify the ability to use ICTs in damping the negative effects of road freight transport on environmental quality. This paper suggests applying ICTs in freight transport to control transport convoy, fuel use, pollution, and efficiency of the traffic system. Another benefit of using ICTs in the transportation sector is limiting the need for physical contacts and, thus, the urban costs (e.g., commuting costs, delays, accidents, etc.).

AUTHOR CONTRIBUTIONS

Formal analysis: Walid Chatti.

Investigation: Walid Chatti.

Methodology: Walid Chatti.

Writing – original draft: Walid Chatti.

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