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RESEARCH ARTICLE

Innovation and CO_2 emissions: the complimentary role of eco-patent and trademark in the OECD economies

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Abstract

Increasing global emissions has led to research on the role of innovations play combating emissions. Mitigations from innovation perspective have mainly been focused on the role of patent, ignoring the role of trademarks. We therefore investigate the mitigating power of patent and trademarks in the OECD economies, benchmarking patent as the traditional mitigation strategy. Examining the complimentary role, we created an interaction term between patent and trademark. Our study divided the OECD economies into four subpanels which are OECD America, OCED Asia, OECD Europe, and OECD Oceania. We employed the Im, Pesaran and Shin W-stat, Augmented Dickey-Fuller, and Phillips Perron unit root tests, as well as cross-sectional dependence and Westerlund cointegration tests for the preliminary test on the variables. We also adopted ARDL approach to cointegration, Granger causality test, and OLS in examining the relationship between CO_2 and patent, trademark, urbanization, and economic growth. Findings show that jointly, eco-patents and trademarks mitigate CO_2 emissions. Also, bidirectional or unidirectional causal relationship was established between our variables of study, an indication that most of our variables can be used in forecasting one other.

Keywords CO_2 emissions · Patent · Trademark · Economic growth · Urbanization

Introduction

Globally, CO_2 emission mitigation has become a major concern to the world as improving the quality of the environment is equally important as pursuing economic success. For several decades, innovation has been marked as an effective way of addressing environmental concerns (Zhang et al. 2017). Economic growth of every nation goes in hand with energy consumption since most sectors require energy to function. In the same vein, urbanization also increases due to the rural-urban drift, consequently leading to the expansion of urban facilities such as housing, conducive roads for travels, among others. According to the urban environmental transition theory, an increase in affluence of cities usually makes manufacturing firms the front-runners in activities that escalate emissions. Liddle (2014) further corroborates the assertion that urbanization may lead to greater energy use and emissions through urbanization's interconnection with industrialization, intensifying environmental pollution.

The global fight towards environmental protection is on the ascendancy, in recent years. Several nations are working towards ways and mechanisms for sustaining the environment. Environmental sustainability is a fundamental principle of economic expansion (Tsai 2017), because an economy's level of CO_2 emissions is linked to economic, social, and industrial factors (Adom et al. 2012). For this reason, most organizations have ended their reactive and short-term strategies in resolving environmental inefficacies, to proactive and innovative

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environmental behaviors (Fraj et al. 2015). The climate mitigation battle demands the participation of fast-growing countries Johansson et al. (2015), since they are more environmentally proactive, comparatively. Abdallh and Abugamos (2017) added that advanced technological progress, environmental regulations, and structural improvements in the economy aid in addressing environmental deterioration.

Environmental proactivity mandates firms to modify their products, processes, and technologies continuously so as to make the environment habitable (Fraj et al. 2015). This implies that both product and process innovation must be devised effectively in addressing environmental pollution. Process innovation encompasses ways of manufacturing, processes, and techniques of production and creation of new equipment for production. Product innovation, on the other hand, introduces a new or significantly improved good or service with respect to its intended uses or characteristics (Schumpeter 1961; Tidd et al. 2005). Process innovations are patented while product innovations obtain trademark. According to Boadu (2016), both trademarks and patents protect inventions. The latter protects a firm's technological knowledge whereas the former protects its marketing assets (Sandner and Block 2011). Being first to apply for a trademark for any services or goods certainly grants one the legitimate right which bans others from using similar trademarks in the same markets (Seip et al. 2018). According to Llerena and Millot (2013), trademarks grant appropriate protection over new technologies just like patents.

Surprisingly, the role innovation plays in environmental pollution reduction has been discussed extensively in literature with focus on only related patents (Popp et al. 2011). Though product and service innovations ameliorate emission levels, their roles are mostly been ignored in literature. Comparatively, patent application takes longer to be granted than trademark application (Zahringer et al. 2018).

This present study, therefore, contributes extensively to literature in two ways: first, we introduce trademark into the innovation-emission nexus to examine the emission abatement power of trademark in the climate change mitigation battle. Again, we examine the role these two intellectual properties (IPs) together play in climate mitigation. This study provides in-depth knowledge on the individual contribution of these two IPs to pollution abatement while employing two key varied models. This current study further examines the interaction term of these two IPs.

Our paper is organized as follows: we proceed with review of related literature in the next section. In the third section, we talk about our data and methods applied. Next, we present results and discussion in the fourth section and then conclude with policy implications in the fifth section.

Literature review

The issue of innovation as an effective means of mitigating climate change is on the ascendency. Extant literature has covered the role environmental innovations towards environmental protections and pollution controls. This section succinctly presents a review of related literature on the following thematic areas: eco-patent and CO_2 emission nexus; role of trademarks; channels for innovation implementation; urbanization and CO_2 emission relationship; and the economic growth, energy consumption, and CO_2 emission nexus.

Eco-patent and CO_2 emission nexus

For several decades, many researchers have employed different methods in identifying the role of innovation on environmental pollution. Some researchers used the IPAT and STIRPAT models for the fact that the environment is impacted by affluence, population, and technology, (Dietz and Rosa 1994; Ehrlich and Holdren 1971; York et al. 2003). Diverse environmentally related technologies have been the focus of some researchers and empirically, they established that environmental innovation significantly decreases CO_2 emissions (Fernández Fernández et al. 2018; Yii and Geetha 2017). The reverse has been found by Mensah et al. (2018) in their individual study on the OECD nations. They attributed this to reluctance on the path of patent owners to transfer technologies and the cost and duration required to obtain patents for innovations. Innovation for environmental concerns comes in two forms which are product innovation and process innovation. Process innovation encompasses technologies invented to enhance production process. Technologies are invented by industries, firms, and individuals to address various needs of which include pollution. Environmental innovation does not only focus on technologies but all other products and services that are created with the aim of greening the environment. Pollution abatement technologies when invented get registered with the patent office as Albino et al. (2014) stated that the purpose of patenting an invention is to protect it. A country's tendency to innovate and patent a climate change technology is subject to their CO_2 emission levels and other GHG emissions (Sua and Moanibab 2017).

Trademark as a tool for innovation

Trademark has been used as a measure of innovation mostly with the focus on product innovation (Gotsch and Hipp 2012; Malmberg and Claes 2018; Millot 2011; Schmoch 2003; Webster and Jensen 2004). Quite a natural strategy for signaling advances of technologies or flagging product innovation is through brand creation (Flikkema et al. 2019). Brands created are associated with trademarks which fulfill two complementary roles. These are identification and differentiation roles. The identification role identifies a product or service from its source and product differentiation role distinguishes one product or service from that of others in a given market (Castaldi 2018a). Trademark aims at expanding and/or sustaining market positions (Castaldi 2018b). This implies that trademarks protect a beginner's brands and marketing assets by excluding others from using them (Block et al. 2014). Trademarks grant exclusion rights that secure competitive advantage and identity for the beginners in their relationship with their customers (Mendonça et al. 2004). It is asserted by Sandner and Block (2011) that trademarks have a positive effect on firm value. Being in the position as a company to set yourself apart technologically and from competition as well as being able to commercialize innovations gives a head way for success and protection of the environment. Trademarks signal a start-up's marketing and technological competences (Zhou et al. 2016). As with patents, trademarks give a measure of the innovative outturn created by companies (Mendonça et al. 2004). Also they could work together with patent, acting as a complementary source of data that inform existent research on the internationalization of innovative activities (Patel and Vega 1999).

Erstwhile studies on innovation-emission nexus have ignored the role trademarks play in curbing emissions, though, both patent and trademarks, can potentially help curb environmental deterioration. Our study therefore extends the current knowledge by investigating the complimentary role of both eco-patent and trademark towards mitigating pollution.

Channels for innovation implementation

Implementation of environmentally related innovation is imperative towards emission mitigation. Finding the right channel to implement innovation is essential as it enhances performance spanning across several areas including pollution control. Marsillac and Roh (2014) are of the view that product innovation moves along with process innovation. A change or modification of a product necessitates a change in its processing and the channel to implement them. There are several channels evident in the literature through which innovations can influence emissions. Innovation improves productivity of capital and/or labor. Additionally, innovation accelerates the technical progress as it allows greater economic output while employing the same level of other inputs. There is the need for staff of firms, industries, and organizations to acquaint themselves with new technologies when innovated. Staff should be enlightened on the benefits of technological innovation to their environmental health. In this regard, embracing new environmental friendly technologies on the production or manufacturing line would not be neglected. Inventing firms, industries, or organizations could transfer environmentally related technologies to other polluting firms when their employees have successfully implemented them.

Research and development (R&D) department or firms or industry with focus towards product and service innovations provides the avenue for enhanced productivity, economic growth, and a shift towards low-carbon energy. R&D department could team up with the marketing department to introduce products and services to consumer as well as educate them on the environmental benefits linked to new products and services to consumer but also the environmental benefits linked to new products and services. In mitigating the environmental repercussions, the brands of the firm and the products and services invented would also enjoy much publicity.

Urbanization and CO_2 emission relationship

Rural-urban migration leads to economic growth which in turn increases energy consumption proliferating emissions (Chang 2010; Mikayilov et al. 2018). Urbanization according to Song et al. (2018) has converted to one of the engines of its economic growth. The urbanization process has concurrently seen enormous number of persons migrate to urban areas from rural areas globally annually (Wang et al. 2018). Urbanization connotes that infrastructure and facilities in the urban cities get expanded. Industries spring up to meet the increasing demand for goods and services. Demand for energy for domestic consumption increases as well. Transport facilities get well patronized as (Wang and He 2015; Xie et al. 2017) associated urban CO_2 emissions with expansion in transport infrastructure. Environmental pollution increases as a result of these which render cities uninhabitable. This implies that urbanization intensifies environmental pressure (Wang et al. 2015). Notwithstanding, to make cities habitable, the compact city theory mandates the creation of green cities which allows high urban density cities to make efficient use of available resources, controlling pollution levels (Burton 2000). Urban green infrastructure planning is geared towards creating green space on inadequate space in the compact cities (Artmann et al. 2019; Richter and Behnisch 2019), for emission mitigation.

The positive side of urbanization is embedded in the negative. It creates challenges as associated increased demand and consumption of energy staggers behind increased CO_2 emission levels (Wang et al. 2014; Zafeiriou and Azam 2017). This has stirred up research (Qin and Wu 2015; Solarin and Lean 2016; Xu et al. 2016). They established that there is a negative impact of urbanization on CO_2 emissions, simply put, urbanization pollutes the environment and the reserve in true in the case of Abdallh and Abugamos (2017) and Wang and Zhao (2018). Findings remain inconclusive hence the need for further studies. Although urbanization leads to economic growth, urban pollution levels could be improved with cleaner energy consumption, process, product, and service innovation.

Economic growth, energy consumption, and CO_2 emission nexus

Economic growth is unachieved without harm to the environment (Naz et al. 2019). This happens because, expanding any economy is accompanied by energy consumption which in the ends increases CO_2 emissions. This has stirred up research on energy consumption and CO_2 emissions (Appiah 2018; Balsalobre-Lorente et al. 2018; Raza et al. 2019). These researchers concluded that energy consumption worsens air quality. Economic growth would more likely surge emissions where energy source is mainly non-renewable Appiah et al. (2019), but a switch to renewable energy would improve environmental quality (Hanif 2018). However, economies rely mostly on non-renewable energy due to lower cost involved in its usage which improves profit levels in the end. One the other hand, Dauda et al. (2019) and Ouyang et al. (2019) found economic growth to improve environmental pollution. Nonetheless, there have been varying findings on economic growth-emission nexus and energy consumption-emission nexus.

The theory of ecological modernization states that environmental-related problems could upswing to an intermediate stage of development from the low; however, inverse impacts could be controlled once there is recognition on the necessity of sustainability of the environment by societies (Abdallh and Abugamos 2017).

Data and methods

Dataset and variables

From the extant literature (Adom et al. 2012; Ali et al. 2017; Boamah et al. 2018), urbanization, economic growth, and energy consumption are believed to largely affect the environment. Therefore, assessing their impact on OECD economies where climate change-related technologies are available is necessary for studies of this nature. Data was gathered from two different sources which are the OECD statistics and the World Development Indicators (WDI) database. The variables CO_2 emissions, urbanization, trademark, and real gross domestic product which we gathered from the World Bank WDI database and the data on eco-patent were gathered from the OECD statistics. For consistency, data for the study period covered 1990 to 2015, reason being that data for all our variables were available for the stated period. Table 1 shows the definition of the variables.

Methodology

Examining the relationship between CO_2 emission, patents, and trademarks, the estimation methods used are the ordinary least squares (OLS) and ARDL cointegration test and the VEC Granger causality test.

The first equation served as a benchmark for our study with the focus on the effect of eco-patent on CO_2 emissions which has attracted much research already. The first and our benchmark equation is given as:

$$CO_2 = \alpha_0 + \beta_1 URB_{it} + \beta_2 RGDP_{it} + \beta_3 PAT_{it} + U_{it} \quad (1)$$

Where CO_2 is the dependent variable. The betas β_1, β_2, and β_3 estimate the coefficients for the regressors. URB represents urbanization, RGDP for economic growth, and PAT for patent application. The subscripts $_i$ and $_t$ imply country and specific period of time, respectively.

Our second equation is a substitution of trademark in place of patent to examine the effect of trademark on CO2 emission abatement.

It is therefore given as:

$$CO_{22} = \alpha_{20} + \beta_{21} URB_{it} + \beta_{22} RGDP_{it} + \beta_{23} TRD_{it} + U_{2it} \quad (2)$$

We introduce the subscript *b* to distinguish the second equation from the benchmark equation. The new variable substituted is *TRD* depicting trademark application.

Our third equation is a presentation of how the 4th equation was developed. The purpose of the fourth equation is to examine the interaction between patents and trademark. We therefore multiplied eco-patent by trademark

$$CO_{23} = \alpha_{30} + \beta_{31} URB_{it} + \beta_{32} RGDP_{it} + \beta_{33} (PAT*TRD)_{it} + U_{3it} \quad (3)$$

We present as:

$$CO_{24} = \alpha_{40} + \beta_{41} URB_{it} + \beta_{42} RGDP_{it} + \beta_{43} PTR_{it} + U_{4it} \quad (4)$$

Where *PTR* becomes the name for the new variable generated. The subscript d here identifies and distinguishes Eq. 3 from the others.

Our final model was built, based on the ARDL cointegration test. This approach examines the short and long-run relationships between patent, trademark, and CO2 emissions.

ARDL is computed in equation as follows:

$$\Delta CO_{2t} = \beta_0 + \sum_{i=1}^{k} \xi_1 \Delta CO_{2t-i} \sum_{i=1}^{k} \xi_2 \Delta RGDP_{t-i} + \sum_{i=1}^{k} \xi_3 \Delta\, URB_{t-i} + \sum_{i=1}^{k} \xi_4 \Delta TRD_{t-i} + \sum_{i=1}^{k} \xi_5 \Delta PAT_{t-i} + \sum_{i=1}^{k} \xi_6 \Delta PTR_{t-i} + \lambda_1 CO_{2t-i} + \lambda_2 RGDP_{t-i} + \lambda_3 URB_{t-i} + \lambda_4 TRD_{t-i} + \lambda_5 PAT_{t-i} + \lambda_5 PTR_{t-i} + \ldots + U_t \ldots \quad (5)$$

Table 1 Variable definitions

Variable	Definition	Source
CO_2	Carbon dioxide emission (kilotons)	World Development Indicators
RGDP	Economic growth (GDP constant USD)	World Development Indicators
URB	Urbanization (urban population)	World Development Indicators
TRD	Trademark (trademark application)	World Development Indicators
PAT	Eco-patent (climate change-related patent)	OECD statistics
PTR	Interaction term between eco-patent and trademark	

CO_2 remains the dependent variable. In this equation, the constant terms in front of the variables represented with β (beta) in the previous equations get replaced with φ (phi) and Ω (ohm). This denotes the changing stage of the variables. The variables with Δ **(**delta) estimate the short-run relationship while that with the Ω (ohm) estimates the long-run relationship.

Results

Westerlund panel cointegration test

Westerlund panel cointegration test developed by Westerlund (2007) is employed when testing for cointegration in a panel data. Results of this test enable researchers to employ the right estimation method. We therefore employed this in testing for cointegration among the variables. Our results displayed in Table 2 clearly rejected the null hypothesis of no-cointegration, Gt (between group), Ga (within group), Pt (between panel), and Pa (among panel).

Panel unit root test

For the purpose of addressing the problem of spurious regression results, the stationarity of the variables of our study was investigated using panel unit root test by Im, Pesaran and Shin W-stat, Augmented Dickey-Fuller (ADF), and Philips Perron (PP) tests and results given in Table 3. All variables passed the test however some were found to be non-stationery at level but turns stationery at 1st difference.

Cross-sectional dependence test

The correlation of the residual in a panel data is tested using cross-sectional dependency test. Three test methods that can be employed are Pesaran CD test, Breusch-Pagan test, and corrected LM test. The test reveals the dependence of the variables in the panels on each other, revealing the correlation among the variables. Table 4 shows our results from this test and it can be clearly seen that the null hypothesis of cross-section independence is rejected in almost all the variables except for real GDP and energy consumption for the OECD America region.

Results of the ordinary least square estimation method

We employed the ordinary least square (OLS) estimation method in examining the relationship among the variables. In the first model, patent was set as the benchmark model. Our model two considered only trademark and the third model considered the interaction term of patent and trademark. Results are displayed in Table 5. Our benchmark model, the entire OECD block reduces emissions by 17% at 1% significance level per unit increase in patents. A decline in emissions by 15% at 5% significance level, 16% at 1% significance level, and 28% at 10% significance level in OECD America, OECD Europe, and OECD Oceania respectively can be

Table 2 Panel Westerlund cointegration test

Region	Statistics	Value	*p* value	Robust *p* value
OECD Panel	Gt	− 2.35	0.23	0.02
	Ga	− 3.81	1.00	0.25
	Pt	− 10.93	0.11	0.00
	Pa	− 3.21	0.99	0.08
OECD America	Gt	− 3.76	0.00	0.00
	Ga	− 5.08	0.88	0.48
	Pt	− 6.39	0.00	0.00
	Pa	− 4.90	0.61	0.42
OECD Asia	Gt	− 3.58	0.00	0.00
	Ga	− 13.10	0.22	0.00
	Pt	− 5.91	0.01	0.00
	Pa	− 12.33	0.07	0.00
OECD Europe	Gt	− 4.47	0.00	0.00
	Ga	− 13.01	0.03	0.00
	Pt	− 17.40	− 0.00	0.00
	Pa	− 12.44	0.00	0.00
OECD Oceania	Gt	− 5.79	0.00	0.00
	Ga	− 16.03	0.11	0.00
	Pt	− 8.69	0.00	0.00
	Pa	− 17.09	0.02	0.00

Table 3 Panel unit root test

Region	Variable	Level Im, Pesaran and Shin W-stat	ADF	PP	1st difference Im, Pesaran and Shin W-stat	ADF	PP
OECD Panel	CO2	− 11.68 (0.00)	243.55 (0.00)	281.86 (0.00)	− 16.52 (0.00)	339.99 (0.00)	1214.95 (0.00)
	RGDP	− 11.52(0.00)	228.96 (0.00)	302.51 (0.00)	− 15.86 (0.00)	327.85 (0.00)	1403.84 (0.00)
	URB	5.90 (1.00)	41.67 (0.79)	74.23 (0.00)	− 0.09 (0.46)	95.47 (0.00)	224.57 (0.00)
	TRD	1.44 (0.92)	50.96 (0.44)	60.47 (0.15)	− 4.05 (0.00)	106.06 (0.00)	184.29 (0.00)
	PAT	1.41 (0.92)	33.26 (0.97)	58.03 (0.20)	− 9.43 (0.00)	211.97 (0.00)	486.86 (0.00)
	EC	− 12.83 (0.00)	251.43 (0.00)	361.80 (0.00)	− 18.31 (0.00)	362.91 (0.00)	1823.52 (0.00)
OECD America	CO2	− 4.86 (0.00)	32.99 (0.00)	34.49 (0.00)	− 6.38 (0.00)	43.80 (0.00)	148.88 (0.00)
	RGDP	− 6.39 (0.00)	43.92 (0.00)	238.12 (0.00)	− 4.59 (0.00)	30.98 (0.00)	33.05 (0.00)
	URB	0.97 (0.83)	3.65 (0.72)	49.34 (0.00)	− 1.90 (0.03)	14.20 (0.02)	6.11 (0.41)
	TRD	− 0.07 (0.47)	5.24 (0.51)	2.40 (0.88)	− 3.73 (0.00)	24.84 (0.00)	33.82 (0.00)
	PAT	1.16 (0.88)	2.33 (0.89)	13.47 (0.04)	− 5.143 (0.00)	35.01 (0.00)	127.11 (0.00)
	EC	− 4.76 (0.00)	32.25 (0.00)	37.10 (0.00)	− 6.39 (0.00)	43.94 (0.00)	232.54 (0.00)
OECD Asia	CO2	− 4.11 (0.00)	27.61 (0.00)	25.14 (0.00)	− 5.59 (0.00)	38.07 (0.00)	128.75 (0.00)
	RGDP	− 3.37 (0.0)	22.94 (0.00)	70.28 (0.00)	− 4.83 (0.00)	32.64 (0.00)	538.47 (0.00)
	URB	− 7.51 (0.00)	77.56 (0.00)	76.31 (0.00)	− 0.24 (0.40)	5.44 (0.49)	553.79 (0.00)
	TRD	− 0.81 (0.21)	7.77 (0.26)	21.88 (0.00)	− 4.13 (0.00)	27.87 (0.00)	397.37 (0.00)
	PAT	0.30 (0.61)	4.38 (0.62)	8.13 (0.23)	− 6.30 (0.00)	42.61 (0.00)	48.86 (0.00)
	EC	− 3.78 (0.00)	25.38 (0.00)	24.68 (0.00)	− 5.70 (0.00)	38.89 (0.00)	197.14 (0.00)
OECD Europe	CO2	− 10.16 (0.00)	163.02 (0.00)	191.24 (0.00)	− 14.30 (0.00)	233.63 (0.00)	780.59 (0.00)
	RGDP	− 9.04 (0.00)	150.13 (0.00)	205.78 (0.00)	− 13.06 (0.00)	226.83 (0.00)	925.99 (0.00)
	URB	3.76 (0.99)	35.81 (0.38)	30.41 (0.64)	− 1.53 (0.06)	68.69 (0.00)	152.55 (0.00)
	TRD	0.45 (0.68)	40.69 (0.20)	53.85 (0.02)	− 3.01 (0.00)	68.17 (0.00)	135.85 (0.00)
	PAT	1.68 (0.95)	19.51 (0.98)	25.27 (0.86)	− 6.27 (0.00)	134.44 (0.00)	335.62 (0.00)
	EC	− 14.04 (0.00)	239.98 (0.00)	1074.33 (0.00)	− 9.90 (0.00)	165.73 (0.00)	243.14 (0.00)
OECD Oceania	CO2	− 4.91 (0.00)	27.60 (0.00)	52.18 (0.00)	− 5.47 (0.00)	30.79 (0.00)	191.71 (0.00)
	RGDP	− 4.80 (0.00)	26.95 (0.00)	38.63 (0.00)	− 5.72 (0.00)	32.22 (0.00)	187.11 (0.00)
	URB	3.84 (0.99)	1.71 (0.79)	7.28 (0.12)	− 4.85 (0.00)	26.90 (0.00)	87.96 (0.00)
	TRD	− 0.56 (0.287)	4.83 (0.31)	2.10 (0.71)	− 3.45 (0.00)	18.82 (0.00)	30.01 (0.00)
	PAT	− 1.48 (0.00)	8.46 (0.08)	8.34 (0.08)	− 5.12 (0.00)	28.69 (0.00)	44.33 (0.00)
	EC	− 4.99 (0.00)	28.15 (0.00)	52.91 (0.00)	− 5.72 (0.00)	32.22 (0.00)	185.42 (0.00)

Note: statistic values on the right, *p* values in parenthesis ()

explained by a unit increase in patent. The mitigating effect of patent on emissions is consistent with the findings of Hodson et al. (2018) and Yii and Geetha (2017). Urbanization rate generates emissions by 12% in the OECD economies. However, in the subpanels, urbanization increases CO_2 emissions by 18% in OECD Europe which confirms the findings but contrasts the findings of Solarin and Shahbaz (2013). Ninety percent of poor air quality in the OECD economics is attributable to economic expansion. Economic growth proliferates emissions by 57% in OECD America, 98% in OECD Asia, and 93% in OECD Europe and this supports the findings of Ahmad and Du (2017), Bekhet et al. (2017), and Saboori et al. (2014).

The second model which focused on the trademarks and CO_2 emissions revealed that trademark has an abatement power owing to the 16% reduction in emissions associated with a unit acquisition of trademarks in the OECD. Also within the subgroups, trademarks curb emissions by 11% in CECD Europe. Energy consumption increases emissions in all the regions and economic growth surges emissions by 69% in OECD America. Urbanization sprouts up CO_2 emissions in the entire OECD economies by 12%. The OECD Europe region increases emissions by 17% in relation to increase in urbanization rate. Findings agree with the findings of Li et al. (2015) and Pata (2018).

A blend of both patents and trademark from model 3 would curb emissions by 2% by the entire panel and 1%, 2%, and 3% in OECD America, OECD Europe, and OECD Oceania, respectively. Energy consumption increases emissions by 57% in OECD America, 94% in OECD Europe, and 66% in OECD

Table 4 Cross-sectional dependence test

Region	Variable	Breusch-Pagan LM	Pesaran scaled LM	Pesaran CD LM
OECD Panel	CO_2	518.36 (0.00)	7.89 (0.00)	− 2.22 (0.00)
	RGDP	542.15 (0.00)	8.32 (0.00)	− 1.07 (0.00)
	URB	3715.13 (0.00)	138.40 (0.00)	28.43 (0.00)
	TRD	1886.44 (0.00)	63.75 (0.00)	12.69 (0.00)
	PAT	4196.53 (0.00)	157.51 (0.00)	61.94 (0.00)
	EC	486.84 (0.00)	6.61 (0.00)	− 1.51 (0.13)
OECD America	CO_2	7.20 (0.07)	0.49 (0.62)	− 0.97 (0.33)
	RGDP	5.16 (0.10)	− 0.34 (0.73)	− 0.40 (0.69)
	URB	71.69 (0.00)	26.81 (0.00)	8.47 (0.00)
	TRD	62.43 (0.00)	23.04 (0.00)	7.90 (0.00)
	PAT	1.163 (0.88)	2.33 (0.89)	13.47 (0.04)
	EC	5.21 (0.16)	− 0.32 (0.75)	− 0.56 (0.57)
OECD Asia	CO2	5.69 (0.13)	− 0.13 (0.90)	− 1.96 (0.05)
	RGDP	15.56 (0.00)	3.90 (0.00)	− 2.79 (0.00)
	URB	27.03 (0.00)	8.59 (0.00)	− 0.59 (0.00)
	TRD	16.74 (0.00)	4.39 (0.00)	0.41 (0.68)
	PAT	39.47 (0.00)	13.66 (0.00)	6.19 (0.00)
	EC	5.94 (0.11)	− 0.024 (0.98)	− 1.79 (0.07)
OECD Europe	CO2	260.10 (0.00)	6.49 (0.00)	− 1.75 (0.00)
	RGDP	265.12 (0.00)	6.80 (0.00)	− 0.83 (0.00)
	URB	1624.85 (0.00)	89.24 (0.00)	15.27 (0.00)
	TRD	675.67 (0.00)	31.69 (0.00)	7.32 (0.00)
	PAT	1681.03 (0.00)	92.65 (0.00)	37.72 (0.00)
	EC	239.51 (0.00)	5.25 (0.00)	− 1.29 (0.00)
OECD Oceania	CO2	− 4.91 (0.00)	27.60 (0.00)	52.17 (0.00)
	RGDP	3.70 (0.05)	0.498 (0.62)	− 1.92 (0.05)
	URB	22.71 (0.00)	13.94 (0.00)	4.77 (0.00)
	TRD	12.98 (0.00)	7.06 (0.00)	3.60 (0.00)
	PAT	14.50 (0.00)	8.13 (0.00)	3.81 (0.00)
	EC	− 4.11 (0.04)	0.78 (0.43)	− 2.03 (0.04)

Note: statistic values on the right, *p* values in parenthesis ()

Oceania. Forty-two percent increase in emissions in OECD America can be explained by an increase in economic growth. Increased urbanization rate surges emissions by 17% by the entire panel and with the subpanels, a 22% in OECD Europe.

ARDL approach to cointegration

For robustness of results, the ARDL approach to cointegration was adopted to examine the short and long-run relationship between CO_2, patent, trademark, urbanization, and energy consumption with findings displayed in Table 6. From our benchmark model which is model 1, patent in the long-run is expected to ameliorate CO_2 emissions by 8% at 1% significant level by the entire OECD block. OECD America and OECD Europe are expected to have a 40% and 5% degeneration in emissions in response to a unit increase in patents, respectively. This ratifies the findings of Mensah et al. (2018). Economic growth in the long-run is estimated to improve the OECD economies at large by 28% but the OECD Oceania subregion is expected to experience environmental degradation of 213%. Energy consumption is anticipated to worsen the environmental quality in the OECD countries at large. A percentage increase in energy consumption would lead to 131% environmental deterioration. OECD Europe is expected to experience 133% dilapidation. Increased urbanization is expected to ameliorate OECD Oceania's emissions level by 427%. Nonetheless, an increase in patent in the short-run is presumed to exacerbate emissions in OECD America by 68%. Urbanization is expected to impair environmental quality in all the subregions.

Model two revealed that trademark is estimated to curtail emissions by 5% in the long-run by the OECD economies but the only subregion that would curb emissions in response to increase in trademark in the long-run is OECD Europe where

Table 5 Results of ordinary least square regression (OLS)

Model 1							
Region	Obs	R^2	Constant	PAT	EC	GDP	URB
OECD Panel	597	0.88	− 12.44 (0.49)	− 0.17 (0.01)***	0.90 (0.02)***	0.02 (0.00)***	0.12 (0.02)***
OECD America	72	0.93	− 15.87 (1.85)	− 0.15 (0.08)**	0.57 (0.17)***	0.42 (0.16)***	0.13 (0.12)
OECD Asia	71	0.90	− 10.21 (1.50)	− 0.03 (0.05)	0.98 (0.05)***	− 0.02 (0.02)	− 0.08 (0.08)
OECD Europe	406	0.90	− 13.94 (0.58)	− 0.16 (0.01)***	0.93 (0.00)***	0.01 (0.01)*	0.18 (0.02)***
OECD Oceania	48	0.92	− 13.09 (4.50)	− 0.28 (0.15)*	0.95 (0.80)	− 0.05 (0.80)	0.20 (0.22)
Model 2							
Region	Obs	R^2	Constant	TRD	EC	GDP	URB
OECD Panel	599	0.85	− 10.82 (0.52)	− 0.16 (0.03)***	0.88 (0.02)***	0.02 (0.01)***	0.12 (0.00)***
OECD America	72	0.92	− 14.39 (1.68)	− 0.21 (0.19)	0.29 (0.07)***	0.69 (0.07)***	0.11 (0.18)
OECD Asia	72	0.90	− 10.36 (1.84)	− 0.09 (0.18)	0.97 (0.05)***	− 0.01 (0.02)	− 0.04 (0.18)
OECD Europe	406	0.87	− 12.60 (0.63)	− 0.11 (0.03)***	0.92 (0.02)***	0.00 (0.01)	0.17 (0.03)***
OECD Oceania	48	0.92	− 5.75 (2.38)	− 0.08 (0.32)	1.82 (0.90)**	− 0.92 (0.89)	− 0.14 (0.21)
Model 3							
Region	Obs	R^2	Constant	PTR	EC	GDP	URB
OECD Panel	597	0.88	− 13.37(0.51)	− 0.02 (0.00)***	0.90 (0.02)***	0.02 (0.01)***	0.17 (0.02)***
OECD America	72	0.93	− 16.99 (2.20)	− 0.01 (0.01)**	0.57 (0.16)***	0.42 (0.16)***	0.20 (0.0.14)
OECD Asia	71	0.90	− 10.60 (1.77)	− 0.00 (0.00)	0.98 (0.05)	− 0.02 (0.02)	− 0.06 (0.10)
OECD Europe	406	0.90	− 14.64 (0.60)	− 0.02 (0.01)***	0.94 (0.02)***	0.01 (0.01)	0.22 (0.03)***
OECD Oceania	48	0.92	− 15.25 (5.32)	− 0.03 (0.02)**	0.66 (0.80)*	− 0.25 (0.88)	0.30 (0.26)

Note: coefficient values on the right, () *t*-statistic values, ***, **, and * denotes 1%, 5%, and 10% significance level, respectively

trademark is estimated to lessen emissions by 5%. Conversely, emissions are expected to worsen in the OECD Oceania where a unit increase in trademarks would escalate emissions by 71%. Economic growth is estimated to deteriorate the entire OECD economies by 146% of which the OECD Europe subregion would experience 130% environmental pollution. Notwithstanding, OECD Oceania would have 186% of clean air. Urbanization would improve emissions in the OECD panel. The entire panel is expected to have 95% improved air quality at the increase rate of urbanization. OECD Europe and Oceania would respectfully experience 127% and 647% clean air. In the short-run, trademark would abate emissions in OECD America and Oceania by 169% and 44% correspondingly. Urbanization again increases CO_2 emissions by1498%. These findings are consistent with the findings of Wang et al. (2017) and Zhou and Liu (2016).

Our novel model's results revealed a long-run relationship between the complimentary role patents play with trademark in the entire OECD and the America and Europe subregions. The total panel would abate emission with this strategy by 1% and then the America and Europe subregions would improve emissions level by 1% and 4%. Economic growth would improve the emissions in the entire panel by 31% and in the OECD Europe as well. OECD Oceania's urbanization rate would lessen emissions by 437%. In the short-run, this strategy would worsen emissions in OECD America and Asia by 5% and 2%, respectively. Urbanization is also estimated to worsen emission in the entire panel by 1313%, 5% in OECD America, and 2006% in the OECD Europe.

Granger causality test

The results of the short and long-run VEC Granger causality test are presented in Table 7. The VECM model is preferred to the VAR in situations where long-run relationship is established (Boamah et al. 2017). Results revealed both long and short-run causality and the short-run established either a unidirectional or bidirectional relationship and for the entire panel, a short-run bidirectional relationship CO_2 emissions and economic growth, CO_2 emissions and energy consumption, economic growth, and energy consumption. A unidirectional causality was found between urbanization and economic growth, urbanization and energy consumption, trademark and patent, economic growth, energy consumption, and the interaction between trademark and patent.

OECD America exhibited a bidirectional relationship between CO_2 emissions and economic growth, CO_2 emissions and energy consumption, patent and economic growth, energy consumption and patent, economic growth, and energy consumption. A unidirectional causal relationship was found between CO2 emissions and urbanization, patent and trademark interaction term and economic growth, patent and trademark interaction term and energy consumption, economic growth

Table 6 Results of the ARDL cointegration estimate

Model 1							
Long-run							
Region	Obs	Model selection	CointEq	EP	GDP	EC	URB
OECD Panel	571	(1, 1, 1, 1, 1)	− 0.96 (0.04)	− 0.08 (0.02)***	− 0.28 (0.16)*	1.31 (0.16)***	− 0.46 (0.38)
OECD America	69	(1, 1, 1, 1, 1)	− 0.93 (0.04)	− 0.40 (0.20)**	1.66 (1.32)	− 0.59 (1.30)	1.77 (1.51)
OECD Asia	67	(1, 1, 1, 1, 1)	− 0.99 (0.03)	− 0.17 (0.18)	2.62 (2.03)	− 1.54 (2.02)	0.61 (1.41)
OECD Europe	388	(1, 1, 1, 1, 1)	− 0.97 (0.05)	− 0.05 (0.02)***	− 0.30 (0.18)	1.33 (0.18)***	− 0.68 (0.45)
OECD Oceania	46	(1, 1, 1, 1, 1)	− 1.28 (0.28)	0.02 (0.16)	2.13 (1.14)*	1.14 (− 1.04)	− 4.27 (1.64)***
Short-run							
Region	AIC	Constant	CointEq	EP	GDP	EC	URB
OECD Panel	1.10	− 4.64 (0.39)	− 0.96 (0.04)	0.04 (0.11)	0.24 (1.02)	− 0.30 (1.01)	13.67 (6.76)
OECD America	1.28	− 47.03 (1.49)	− 0.93 (0.04)	0.68 (0.37)*	4.16 (5.73)	− 4.17 (5.74)	58.35 (13.13)***
OECD Asia	1.63	− 36.57 (4.02)	− 0.99 (0.03)	0.19 (0.12)	0.48 (1.01)	− 0.55 (1.00)	6.97 (2.91)**
OECD Europe	1.01	− 1.55 (0.38)	− 0.97 (0.05)	− 0.03 (0.12)	0.37 (0.66)	− 0.45 (0.67)	19.28 (9.02)**
OECD Oceania	0.82	65.52 (18.36)	− 1.28 (0.28)	− 0.30 (0.23)	− 3.72 (6.04)	3.43 (5.80)	15.76 (2.37)***
Model 2							
Long-run							
Region	Obs	Model selection	CointEq	TRD	GDP	EC	URB
OECD Panel	574	(1, 1, 1, 1, 1)	− 0.96 (0.05)	− 0.05 (0.02)***	− 0.44 (0.19)***	1.46 (0.18)***	− 0.95 (0.35)***
OECD America	69	(1, 1, 1, 1, 1)	− 0.89 (0.10)	0.54 (0.49)	− 0.82 (1.58)	1.85 (1.57)	− 1.03 (2.38)
OECD Asia	69	(1, 1, 1, 1, 1)	− 0.96 (0.04)	− 0.28 (0.26)	3.20 (1.65)*	− 2.12 (1.64)	− 1.89 (1.45)
OECD Europe	390	(1, 1, 1, 1, 1)	− 0.94 (0.05)	− 0.05 (0.02)***	− 0.27 (0.19)	1.30 (0.19)***	− 1.27 (0.37)***
OECD Oceania	46	(1, 1, 1, 1, 1)	− 1.48 (0.09)	0.71 (0.15)***	2.80 (0.79)***	− 1.86 (0.79)**	− 6.47 (1.35)***
Short-run							
Region	AIC	Constant	CointEq	TRD	GDP	EC	URB
OECD Panel	0.13	3.82 (0.35)	− 0.96 (0.05)	− 0.02 (0.26)	0.48 (0.99)	− 0.54 (0.98)	14.98 (7.95)*
OECD America	1.32	0.35 (1.10)	− 0.89 (0.10)	− 1.69 (0.62)***	5.54 (5.33)	− 5.50 (5.28)	6.51 (14.13)
OECD Asia	1.64	5.24 (6.24)	− 0.96 (0.04)	0.26 (0.66)	1.40 (1.30)	− 1.44 (1.34)	3.25 (12.85)
OECD Europe	0.82	65.52 (18.36)	− 0.94 (0.05)	− 0.30 (0.23)	− 3.72 (6.04)	3.43 (5.80)	15.76 (2.37)***
OECD Oceania	0.90	113.58 (0.59)	− 1.48 (0.09)	− 0.44 (19.68)*	− 6.13 (4.05)	5.66 (4.14)	4.85 (19.68)
Model 3							
Long-run							
Region	Obs	Model selection	CointEq	PTR	GDP	EC	URB
OECD Panel	571	(1, 1, 1, 1, 1)	− 0.95 (0.04)	− 0.01 (0.01)***	− 0.31 (0.17)*	1.33 (0.16)***	− 0.46 (0.22)
OECD America	69	(1, 1, 1, 1, 1)	− 0.94 (0.04)	− 0.04 (0.02)**	1.98 (1.34)	− 0.91 (1.33)	1.90 (1.52)
OECD Asia	67	(1, 1, 1, 1, 1)	− 0.96 (0.02)	− 0.01 (0.02)	3.15 (2.05)	− 2.08 (2.04)	0.19 (1.37)
OECD Europe	388	(1, 1, 1, 1, 1)	− 0.96 (0.05)	− 0.01 (0.00)***	− 0.31 (0.18)*	1.35 (0.18)***	− 0.67 (0.45)
OECD Oceania	46	(1, 1, 1, 1, 1)	68.70 (18.47)	0.01 (0.02)	1.86 (1.12)	− 0.92 (1.11)	− 4.37 (1.70)***
Short-run							
Region	AIC	Constant	CointEq	PTR	GDP	EC	URB
OECD Panel	1.11	− 4.52 (0.40)	− 0.95 (0.04)	0.01 (0.01)	0.28 (1.01)	− 0.34 (0.99)	13.13 (6.75)**
OECD America	1.29	− 50.18 (2.21)	− 0.94 (0.04)	0.05 (0.03)*	4.37 (5.77)	− 4.40 (5.78)	0.05 (0.03)***
OECD Asia	1.61	− 30.96 (5.67)	− 0.96 (0.02)	0.02 (0.02)**	0.57 (1.21)	− 0.60 (1.21)	6.46 (4.11)
OECD Europe	1.03	− 1.86 (0.40)	− 0.96 (0.05)	0.00 (0.01)	0.25 (0.67)	− 0.33 (0.68)	20.06 (9.11)**
OECD Oceania	46	0.84	68.70 (18.47)	68.70 (18.47)	− 0.03 (0.02)	− 3.61 (6.03)	3.31 (5.79)

Note: coefficient values on the right, *t*-statistic values (), ***, **, and * denote 1%, 5%, and 10%, respectively

and trademark, energy consumption, and patent and trademark interaction term.

A bidirectional relationship was found between CO_2 emissions and economic growth, CO_2 emissions and energy consumption, energy consumption and economic growth, trademark and economic growth, energy consumption, and trademark in OECD Asia. Also, a unidirectional causal relationship was found between CO2 emissions and patent, CO_2 emissions and trademarks, economic growth and energy consumption, energy consumption, and patent.

In the OECD Europe subregion, a bidirectional causality was found between CO_2 emissions and economic growth, energy consumption and CO_2 emissions, economic growth and patents, economic growth, and energy consumption. On the other hand, a unidirectional relationship was found between patent and energy consumption, urbanization and economic growth, urbanization and energy consumption, trademark and patent, trademark and economic growth, trademark, and the interaction between trademark and patent. The interaction between patent and trademark Granger causes economic growth and energy consumption hence a unidirectional relationship established.

CO_2 emissions have a bidirectional relationship with patent and trademark in OECD Oceania subpanel. Economic growth has a unidirectional relationship with patent, trademark, and patent and trademark interaction term. A unidirectional relationship was established between energy consumption and patent, trademark, and the interaction term of the patent and trademark. The interaction variable Granger causes CO_2 emissions as well in the OECD Oceania subregion.

Discussion

In our attempt to examine the relationship between patent, trademarks, and CO_2 emissions, three models were built: ordinary least square (OLS), ARDL approach to cointegration, and Granger causality test used for our estimation. We benchmarked the first model, where we focused on patent which has been the orthodox method by researchers to examine the innovation-emission nexus. From the OLS of our benchmark model, patent mitigates emissions at the entire panel level and in the OECD America, Europe, and Oceania subregions. This could be attributed to number of environmental-related patents registered in the OECD economies annually. Much concerns have been focused on creation of green technologies by these economies lately to address their pollution problems hence an increasing trend in such patents over the past years.

The second model revealed abatement power of trademark. Emission levels are reduced per unit increase in trademark application in the entire OECD and Europe subgroup. Undoubtedly, this finding affirms that trademarks fulfill a specific role of flagging the introduction of the new product (Seip et al. 2018), hence necessary to implement in a product's life cycle. The third model factors in both strategy and results seemed satisfactory. Combining these two could go a long was to solve pollution problems in the OECD economies. This affirms the assertion of Thomä and Bizer (2013) and Zhou et al. (2016) that firms apply for both trademarks and patents so as to complement each other.

ARDL approach to cointegration's results from our benchmark model renders a positive feedback on patent-CO_2 emission nexus where patent minimizes the negative consequences of human activities on the environment in the long-run. From the second model, equally trademark is estimated to abate emission in the long-run at the panel level and three other subgroups as the benchmark model. Also, it is estimated to curb emissions in the short-run in the two of the subpanel implying the strong effect of this concept on the improvement of environmental quality in the OECD. In the long-run, our novel strategy is expected to curb emissions in the entire panel and two other subsets. This endorses the statement of Thoma (2015) who is of the view that both strategies function as a signaling device and extend patent protection. However, in the short-run, this strategy would worsen emissions in the OECD economies.

Cross-examination

Deviating from the orthodox method of focusing on eco-patents in addressing environmental pollution, we introduce trademark to examine its mitigation power as well. As much as patents are able to improve emission level in the OECD, trademark was found to be helpful in that wise too. Our benchmark model proved a positive effect of patent on CO_2 emissions so as trademark. This implies that the two can be much helpful in improving environmental quality. From our novel model, putting together these two would go a long way to protect the environment. Based on the assertion that patent applied, consequently granted are relatively few hence limited accessibility (Mensah et al. 2018). Product innovations could earn trademarks and process innovations could earn patents. Products aimed at addressing emissions could equally earn trademark hence appropriate to combine the two in the fight against environmental pollution.

Theoretical implication of our study

The focus of the Intergovernmental Panel on Climate Change (IPCC) on the global climate change battle by 2030 makes this study timely as its findings provide the role trademarks and eco-patents play in emission reduction.

From the theoretical perspective, this study extends the theory on innovation as it tests key hypotheses to provide better inferences. Our study revealed that trademarks are equally important in improving emission levels and this is related to product and service innovations. Investing in product and service innovations aimed at protecting the environment is very necessary to this course. In this regard, it is evident that encouraging product and service innovations aimed at addressing environmental concerns would address pollution issues related to transport and cities. Automobile industries could come up with less polluting vehicular brands and more estate developers would move into the compact city niche to create eco-cities.

Conclusion and policy implications

This paper attempted to address the issues of increased CO_2 emissions in the OECDs by treading a new path. Trademark was introduced in addressing high emission rate against the traditional patent-emission nexus. The ARDL approach to cointegration and ordinary least square (OLS), and Granger causality test were the methods used. Empirically, we found that patent and trademark can combat emissions in the OECD economies, notwithstanding, trademark curbs emissions better. We also found that economic growth and urbanization increase CO_2 emissions. A unidirectional relationship was found between trademark and CO_2 emissions as well as urbanization and CO_2 emissions.

Table 7 VECM Granger causality test (short-run/long-run causality)

Panel		ΔCO_2	ΔEP	ΔRGDP	ΔEC	ΔURB	ΔTRD	ΔPTR	ECT
	CO_2	–	0.50 (0.78)	18.12 (0.00)***	19.84 (0.00)***	2.08 (0.35)	2.12 (0.35)	0.64 (0.73)	− 0.03 [− 2.39] (0.02)**
	EP	0.71 (0.70)	–	1.06 (0.59)	1.46 (0.48)	0.66 (0.72)	125.96 (0.00)***	0.34 (0.84)	0.01 [2.17] (0.03)**
	RGDP	9.22 (0.01)***	1.56 (0.46)	–	6.95 (0.03)**	6.31 (0.04)**	14.09 (0.00)***	0.44 (0.80)	− 0.02 [− 1.54] (0.12)
	EC	8.52 (0.01)***	1.48 (0.48)	17.95 (0.00)***	–	6.72 (0.03)**	14.29 (0.00)***	0.40 (0.82)	− 0.02 [− 2.18] (0.03)**
	URB	0.33 (0.85)	0.66 (0.72)	2.03 (0.36)	0.48 (0.79)	–	3.89 (0.14)	1.09 (0.58)	0.00 [0.02] (0.57]
	TRD	0.27 (0.87)	0.28 (0.87)	0.24 (0.89)	0.29 (0.86)	0.13 (0.94)	–	0.30 (0.86)	0.03 [16.47] (0.00)***
	PTR	0.04 (0.99)	0.54 (0.76)	0.39 (0.82)	0.42 (0.81)	0.72 (0.70)	135.06 (0.00)***	–	0.07 [2.16] (0.03)**
Region		ΔCO_2	ΔEP	ΔRGDP	ΔEC	ΔURB	ΔTRD	ΔPTR	ECT
OECD America	CO_2	–	0.47 (0.79)	4.86 (0.09)*	4.87 (0.09)*	0.68 (0.71)	0.75 (0.69)	0.46 (0.79)	− 0.90 [− 5.11] (0.00)***
	EP	2.42 (0.30)	–	5.60 (0.06)*	5.61 (0.06)*	1.12 (0.57)	0.64 (0.73)	0.83 (0.66)	0.01 [0.28] (0.78)
	RGDP	6.90 (0.03)**	4.69 (0.09)*	–	7.59 (0.02)**	0.48 (0.79)	0.50 (0.78)	5.47 (0.07)*	− 0.91 [0.04] (0.00)***
	EC	6.99 (0.03)**	4.65 (0.09)*	7.88 (0.02)**	–	0.52 (0.77)	0.50 (0.78)	5.43 (0.07)*	− 0.92 [0.16] (0.00)***
	URB	8.62 (0.01)***	0.42 (0.81)	10.72 (0.00)***	10.89 (0.00)***	–	0.83 (0.71)	0.67 (0.71)	− 0.00 [− 0.36] (0.36)
	TRD	2.23 (0.32)	2.15 (0.34)	3.51 (0.17)	3.53 (0.17)	3.09 (0.21)		1.79 (0.41)	− 0.01 [− 0.77] (0.45)
	PTR	2.35 (0.31)	1.21 (0.55)	5.36 (0.07)*	5.36 (0.07)*	1.08 (0.83)	0.56 (0.77)	–	− 0.03 [0.51] (0.96)
OECD Asia	CO_2	–	2.08 (0.35)	9.79 (0.01)***	9.83 (0.01)***	0.24 (0.85)	3.35 (0.19)	1.78 (0.41)	− 0.35 [− 5.28] (0.00)***
	EP	5.76 (0.06)*	–	8.71 (0.01)***	8.77 (0.01)***	2.10 (0.35)	1.05 (0.59)	3.80 (0.15)	− 0.01 [− 0.56] (0.58)
	RGDP	6.17 (0.05)**	0.74 (0.69)	–	5.37 (0.07)*	2.80 (0.25)	5.40 (0.07)*	1.62 (0.45)	− 0.39 [− 6.94] (0.00)***
	EC	6.05 (0.05)**	0.98 (0.61)	5.45 (0.07)*	–	2.13 (0.35)	5.22 (0.07)*	1.92 (0.38)	− 0.39 [− 7.01] (0.00)***
	URB	1.03 (0.60)	2.43 (0.30)	3.03 (0.22)	3.07 (0.22)	–	2.52 (0.28)	2.20 (0.33)	0.00 [2.30] (0.03)**
	TRD	4.89 (0.09)*	4.45 (0.11)	7.18 (0.03)**	7.14 (0.03)**	4.04 (0.13)	–	2.37 (0.31)	0.01 [1.79] (0.08)*
	PTR	6.84 (0.03)**	4.20 (0.12)	9.57 (0.01)	9.68 (0.01)***	1.97 (0.37)	1.20 (0.55)	–	− 0.01 [− 0.05] (0.96)
OECD Europe	CO_2	–	0.33 (0.85)	9.65 (0.01)***	13.16 (0.00)***	0.52 (0.77)	0.65 (0.72)	0.51 (0.78)	− 0.02 [− 1.65] (0.09)*
	EP	0.49 (0.78)	–	1.38 (0.50)	1.19 (0.55)	0.99 (0.61)	79.25 (0.00)***	1.11 (0.57)	0.00 [1.24] (0.22)
	RGDP	10.63 (0.00)***	17.73 (0.00)***	–	6.78 (0.03)**	4.66 (0.09)*	4.74 (0.09)*	18.92 (0.00)***	− 0.01 [− 0.44] (0.66)
	EC	9.97 (0.01)***	17.67 (0.00)***	8.97 (0.01)***	–	4.53 (0.10)	4.55 (0.12)	18.92 (0.00)**	− 0.02 [− 1.40] (0.16)
	URB	0.91 (0.63)	1.06 (0.59)	0.15 (0.93)	1.27 (0.53)	–	0.68 (0.71)	1.34 (0.51)	0.00 [0.27] (0.79)
	TRD	0.15 (0.93)	0.14 (0.93)	0.24 (0.89)	0.25 (0.88)	0.51 (0.77)	–	0.22 (0.90)	0.03 [14.18] (0.00)***
	PTR	0.01 (0.99)	0.43 (0.81)	1.01 (0.60)	0.31 (0.86)	0.67 (0.72)	83.91 (0.00)***	–	0.05 [1.36] (0.17)
OECD Oceania	CO_2	–	8.65 (0.01)***	0.34 (0.85)	0.34 (0.84)	4.29 (0.12)	4.90 (0.09)*	10.38 (0.01)***	0.88 [2.82] (0.01)***
	EP	13.62 (0.00)***		13.19 (0.00)***	13.40 (0.00)***			1.09 (0.58)	− 0.08 [− 1.63] (0.11)
	RGDP	0.19 (0.91)	3.42 (0.18)	–	0.40 (0.82)	1.73 (0.42)	1077 (0.41)	3.39 (0.18)	1.05 [3.23] (0.00)***
	EC	0.21 (0.90)	3.81 (0.15)	0.31 (0.85)	–	1.81 (0.41)	1.81 (0.40)	3.72 (0.16)	1.05 [3.26] (0.00)***
	URB	0.28 (0.87)	4.12 (0.13)	0.98 (0.61)	0.99 (0.61)	–	3.93 (0.14)	3.97 (0.14)	− 0.00 [− 1.70] (0.10)
	TRD	9.24 (0.01)***	2.87 (0.24)	10.06 (0.01)***	10.23 (0.01)***	0.83 (0.66)	–	3.19 (0.20)	− 0.05 [− 2.82] (0.01)***
	PTR	(13.54)***	0.38 (0.83)	13.15 (0.01)***	13.36 (0.00)***	2.64 (0.27)	3.61 (0.16)	–	− 0.79 [− 1.55] (0.13)

Note: coefficient values on the right, ***, **, and * denote 1%, 5%, and 10%, respectively. [] *t*-statistic values, () *p* values

We propose policies based on our findings. Government and policy makers should encourage individuals and industries to move into registration of trademarks when they have been able to innovate climate mitigation products, processes, services, and technologies. Industries would be moved to improvise environmental-related technologies, better production process, among others which could earn them trademark followed by patent. Knowing that one's innovation could protect the environment and yield profit would inspire people to innovate at all levels. This would help address the emission issues in the OECDs.

Trademark and patent applications should be encouraged in all sectors of the OECD economies. This would motivate people to innovate pollution abatement products and innovatively render services that contribute to the climate mitigation battle because they could obtain either of the above stated IPs to guard their inventions from copyright, more importantly, one which is easily attainable comparatively, as both offer protection for innovations on one hand, and grants financial benefit to owners.

Limitation of the study and direction for future research

Our study examined the impact of innovation and environmental pollution in the OECD economies comparing the abatement power of two IPs, eco-patents and trademarks using environmentally related patent and trademark application data. We recommend that further studies analyze the influence of innovation on the environment while capturing the clear role of registered trademarks.

Further research may also investigate the impact of innovation on the environment from other jurisdiction. This is to help ascertain the intensity of the impact of innovation across various regions.

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References

Abdallh AA, Abugamos H (2017) A semi-parametric panel data analysis on the urbanisation-carbon emissions nexus for the MENA countries. Renew Sust Energ Rev 78:1350–1356. https://doi.org/10.1016/j.rser.2017.05.006

Adom PK, Bekoe W, Amuakwa-Mensah F, Mensah JT, Botchway E (2012) Carbon dioxide emissions, economic growth, industrial structure, and technical efficiency: empirical evidence from Ghana, Senegal, and Morocco on the causal dynamics. Energy 47:314–325

Ahmad N, Du L (2017) Effects of energy production and CO2 emissions on economic growth in Iran: ARDL approach. Energy 123:521–537. https://doi.org/10.1016/j.energy.2017.01.144

Albino V, Ardito L, Dangelico RM, Messeni Petruzzelli A (2014) Understanding the development trends of low-carbon energy technologies: a patent analysis. Appl Energy 135:836–854. https://doi.org/10.1016/j.apenergy.2014.08.012

Ali HS, Abdul-Rahim A, Ribadu MB (2017) Urbanization and carbon dioxide emissions in Singapore: evidence from the ARDL approach. Environ Sci Pollut Res 24:1967–1974. https://doi.org/10.1007/s11356-016-7935-z

Appiah MO (2018) Investigating the multivariate Granger causality between energy consumption, economic growth and CO2 emissions in Ghana. Energy Policy 112:198–208. https://doi.org/10.1016/j.enpol.2017.10.017

Appiah K, Du J, Yeboah M, Appiah R (2019) Causal correlation between energy use and carbon emissions in selected emerging economies—panel model approach. Environ Sci Pollut Res 26:7896–7912. https://doi.org/10.1007/s11356-019-04140-2

Artmann M, Kohler M, Meinel G, Gan J, Ioja I-C (2019) How smart growth and green infrastructure can mutually support each other—a conceptual framework for compact and green cities. Ecol Indic 96:10–22. https://doi.org/10.1016/j.ecolind.2017.07.001

Balsalobre-Lorente D, Shahbaz M, Roubaud D, Farhani S (2018) How economic growth, renewable electricity and natural resources contribute to CO2 emissions? Energy Policy 113:356–367. https://doi.org/10.1016/j.enpol.2017.10.050

Bekhet HA, Matar A, Yasmin T (2017) CO2 emissions, energy consumption, economic growth, and financial development in GCC countries: dynamic simultaneous equation models. Renew Sust Energ Rev 70:117–132. https://doi.org/10.1016/j.rser.2016.11.089

Block JH, De Vries G, Schumann JH, Sandner P (2014) Trademarks and venture capital valuation. J Bus Ventur 29:525–542. https://doi.org/10.1016/j.jbusvent.2013.07.006

Boadu FO (2016) Chapter 7—trademarks and patents. In: Boadu FO (ed) Agricultural law and economics in Sub-Saharan Africa. Academic Press, San Diego, pp 215–262. https://doi.org/10.1016/B978-0-12-801771-5.00007-1

Boamah KB, Du J, Bediako IA, Boamah AJ, Abdul-Rasheed AA, Owusu SM (2017) Carbon dioxide emission and economic growth of China—the role of international trade. Environ Sci Pollut Res 24:13049–13067. https://doi.org/10.1007/s11356-017-8955-z

Boamah KB, Du J, Boamah AJ, Appiah K (2018) A study on the causal effect of urban population growth and international trade on environmental pollution: evidence from China. Environ Sci Pollut Res 25:5862–5874

Burton E (2000) The compact city: just or just compact? A preliminary analysis. Urban Stud 37:1969–2001

Castaldi C (2018a) To trademark or not to trademark: the case of the creative and cultural industries. Res Policy 47:606–616. https://doi.org/10.1016/j.respol.2018.01.006

Castaldi C (2018b) To trademark or not to trademark: the case of the creative and cultural industries. Res Policy 47:606–616. https://doi.org/10.1016/j.respol.2018.01.006

Chang C-C (2010) A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China. Appl Energy 87:3533–3537. https://doi.org/10.1016/j.apenergy.2010.05.004

Dauda L, Long X, Mensah CN, Salman M (2019) The effects of economic growth and innovation on CO2 emissions in different regions. Environ Sci Pollut Res 26:15028–15038. https://doi.org/10.1007/s11356-019-04891-y

Dietz T, Rosa EA (1994) Rethinking the environmental impacts of population, affluence and technology. Hum Ecol Rev 1:277–300

Ehrlich PR, Holdren JP (1971) Impact of population growth. Science 171:1212–1217

Fernández Fernández Y, Fernández López MA, Olmedillas Blanco B (2018) Innovation for sustainability: the impact of R&D spending on CO2 emissions. J Clean Prod 172:3459–3467. https://doi.org/10.1016/j.jclepro.2017.11.001

Flikkema M, Castaldi C, de Man A-P, Seip M (2019) Trademarks' relatedness to product and service innovation: a branding strategy approach. Res Policy 48:1340–1353. https://doi.org/10.1016/j.respol.2019.01.018

Fraj E, Matute J, Melero I (2015) Environmental strategies and organizational competitiveness in the hotel industry: the role of learning and innovation as determinants of environmental success. Tour Manag 46:30–42

Gotsch M, Hipp C (2012) Measurement of innovation activities in the knowledge-intensive services industry: a trademark approach. Serv Ind J 32:2167–2184. https://doi.org/10.1080/02642069.2011.574275

Hanif I (2018) Impact of economic growth, nonrenewable and renewable energy consumption, and urbanization on carbon emissions in Sub-Saharan Africa. Environ Sci Pollut Res 25:15057–15067. https://doi.org/10.1007/s11356-018-1753-4

Hodson EL, Brown M, Cohen S, Showalter S, Wise M, Wood F, Caron J, Feijoo F, Iyer G, Cleary K (2018) U.S. energy sector impacts of technology innovation, fuel price, and electric sector CO2 policy: results from the EMF 32 model intercomparison study. Energy Econ 73:352–370. https://doi.org/10.1016/j.eneco.2018.03.027

Johansson DJA, Lucas PL, Weitzel M, Ahlgren EO, Bazaz AB, Chen W, den Elzen MGJ, Ghosh J, Grahn M, Liang QM, Peterson S, Pradhan BK, van Ruijven BJ, Shukla PR, van Vuuren DP, Wei YM (2015) Multi-model comparison of the economic and energy implications for China and India in an international climate regime. Mitig Adapt Strateg Glob Chang 20:1335–1359. https://doi.org/10.1007/s11027-014-9549-4

Li F, Dong S, Li S, Li Z, Li Y (2015) Measurement and scenario simulation of effect of urbanisation on regional CO2 emissions based on UEC-SD model: a case study in Liaoning Province, China. Chin Geogr Sci 25:350–360. https://doi.org/10.1007/s11769-014-0729-7

Liddle B (2014) Impact of population, age structure, and urbanization on carbon emissions/energy consumption: evidence from macro-level, cross-country analyses. Popul Environ 35:286–304. https://doi.org/10.1007/s11111-013-0198-4

Llerena P, Millot V (2013) Are trade marks and patents complementary or substitute protections for innovation. In: Bureau d′économie théorique et appliquée Document de Travail, 1

Malmberg, Claes (2018) Trademarks statistics as innovation indicator?: a micro study

Marsillac E, Roh JJ (2014) Connecting product design, process and supply chain decisions to strengthen global supply chain capabilities. Int J Prod Econ 147:317–329

Mendonça S, Pereira TS, Godinho MM (2004) Trademarks as an indicator of innovation and industrial change. Res Policy 33:1385–1404

Mensah CN, Long X, Boamah KB, Bediako IA, Dauda L, Salman M (2018) The effect of innovation on CO2 emissions of OCED countries from 1990 to 2014. Environ Sci Pollut Res 25:29678–29698. https://doi.org/10.1007/s11356-018-2968-0

Mikayilov JI, Galeotti M, Hasanov FJ (2018) The impact of economic growth on CO2 emissions in Azerbaijan. J Clean Prod 197:1558–1572. https://doi.org/10.1016/j.jclepro.2018.06.269

Millot V (2011) Firms' intangible assets: who relies on trademarks? Analysis of French and German firms' trademarking behaviour

Naz S, Sultan R, Zaman K, Aldakhil AM, Nassani AA, Abro MMQ (2019) Moderating and mediating role of renewable energy consumption, FDI inflows, and economic growth on carbon dioxide emissions: evidence from robust least square estimator. Environ Sci Pollut Res 26:2806–2819. https://doi.org/10.1007/s11356-018-3837-6

Ouyang X, Shao Q, Zhu X, He Q, Xiang C, Wei G (2019) Environmental regulation, economic growth and air pollution: panel threshold analysis for OECD countries. Sci Total Environ 657:234–241. https://doi.org/10.1016/j.scitotenv.2018.12.056

Pata UK (2018) The effect of urbanization and industrialization on carbon emissions in Turkey: evidence from ARDL bounds testing procedure. Environ Sci Pollut Res 25:7740–7747. https://doi.org/10.1007/s11356-017-1088-6

Patel P, Vega M (1999) Patterns of internationalisation of corporate technology: location vs. home country advantages. Res Policy 28:145–155

Popp D, Hascic I, Medhi N (2011) Technology and the diffusion of renewable energy. Energy Econ 33:648–662

Qin B, Wu J (2015) The form of urbanization and carbon emissions in China: a panel data analysis across the provinces 2000–2008. In: Wong T-C, Han SS, Zhang H (eds) Population mobility, urban planning and management in China. Springer International Publishing, Cham, pp 113–125. https://doi.org/10.1007/978-3-319-15257-8_7

Raza SA, Shah N, Sharif A (2019) Time frequency relationship between energy consumption, economic growth and environmental degradation in the United States: evidence from transportation sector. Energy 173:706–720. https://doi.org/10.1016/j.energy.2019.01.077

Richter B, Behnisch M (2019) Integrated evaluation framework for environmental planning in the context of compact green cities. Ecol Indic 96:38–53. https://doi.org/10.1016/j.ecolind.2018.05.025

Saboori B, Sapri M, bin Baba M (2014) Economic growth, energy consumption and CO2 emissions in OECD (Organization for Economic Co-operation and Development)'s transport sector: a fully modified bi-directional relationship approach. Energy 66:150–161. https://doi.org/10.1016/j.energy.2013.12.048

Sandner PG, Block J (2011) The market value of R&D, patents, and trademarks. Res Policy 40:969–985. https://doi.org/10.1016/j.respol.2011.04.004

Schmoch U (2003) Service marks as novel innovation indicator. Res Eval 12:149–156

Schumpeter JA (1961) The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle (1912/1934) Google Scholar

Seip M, Castaldi C, Flikkema M, De Man A-P (2018) The timing of trademark application in innovation processes. Technovation 72-73:34–45. https://doi.org/10.1016/j.technovation.2018.02.001

Solarin SA, Lean HH (2016) Natural gas consumption, income, urbanization, and CO2 emissions in China and India. Environ Sci Pollut Res 23:18753–18765. https://doi.org/10.1007/s11356-016-7063-9

Solarin SA, Shahbaz M (2013) Trivariate causality between economic growth, urbanisation and electricity consumption in Angola: cointegration and causality analysis. Energy Policy 60:876–884. https://doi.org/10.1016/j.enpol.2013.05.058

Song C, Liu Q, Gu S, Wang Q (2018) The impact of China's urbanization on economic growth and pollutant emissions: an empirical study based on input-output analysis. J Clean Prod 198:1289–1301. https://doi.org/10.1016/j.jclepro.2018.07.058

Sua H-N, Moanibab IM (2017) Does innovation respond to climate change? Empirical evidence from patents and greenhouse gas emissions. Technol Forecast Soc Chang 122:49–62

Thoma G (2015) Trademarks and the patent premium value: evidence from medical and cosmetic products. World Patent Inf 41:23–30. https://doi.org/10.1016/j.wpi.2015.02.003

Thomä J, Bizer K (2013) To protect or not to protect? Modes of appropriability in the small enterprise sector. Res Policy 42:35–49. https://doi.org/10.1016/j.respol.2012.04.019

Tidd J, Bessant J, Pavitt K (2005) Managing innovation integrating technological, market and organizational change. John Wiley and Sons Ltd, Hoboken
Tsai W-T (2017) Green public procurement and green-mark products strategies for mitigating greenhouse gas emissions—experience from Taiwan. Mitig Adapt Strateg Glob Chang 22:729–742. https://doi.org/10.1007/s11027-015-9695-3
Wang J, He D (2015) Sustainable urban development in China: challenges and achievements. Mitig Adapt Strateg Glob Chang 20: 665–682. https://doi.org/10.1007/s11027-015-9644-1
Wang Y, Zhao T (2018) Impacts of urbanization-related factors on CO2 emissions: evidence from China's three regions with varied urbanization levels. Atmos Pollut Res 9:15–26. https://doi.org/10.1016/j.apr.2017.06.002
Wang S, Fang C, Guan X, Pang B, Ma H (2014) Urbanisation, energy consumption, and carbon dioxide emissions in China: a panel data analysis of China's provinces. Appl Energy 136:738–749. https://doi.org/10.1016/j.apenergy.2014.09.059
Wang S, Fang C, Wang Y, Huang Y, Ma H (2015) Quantifying the relationship between urban development intensity and carbon dioxide emissions using a panel data analysis. Ecol Indic 49:121–131. https://doi.org/10.1016/j.ecolind.2014.10.004
Wang S, Liu X, Zhou C, Hu J, Ou J (2017) Examining the impacts of socioeconomic factors, urban form, and transportation networks on CO2 emissions in China's megacities. Appl Energy 185:189–200. https://doi.org/10.1016/j.apenergy.2016.10.052
Wang S, Li G, Fang C (2018) Urbanization, economic growth, energy consumption, and CO2 emissions: empirical evidence from countries with different income levels. Renew Sust Energ Rev 81:2144–2159. https://doi.org/10.1016/j.rser.2017.06.025
Webster E, Jensen P (2004) Patterns of trademarking activity in Australia, vol 15
Westerlund J (2007) Testing for error correction in panel data. Oxf Bull Econ Stat 69:709–748
Xie R, Fang J, Liu C (2017) The effects of transportation infrastructure on urban carbon emissions. Appl Energy 196:199–207. https://doi.org/10.1016/j.apenergy.2017.01.020
Xu S-C, He Z-X, Long R-Y, Shen W-X, Ji S-B, Chen Q-B (2016) Impacts of economic growth and urbanization on CO2 emissions: regional differences in China based on panel estimation. Reg Environ Chang 16:777–787. https://doi.org/10.1007/s10113-015-0795-0
Yii K-J, Geetha C (2017) The nexus between technology innovation and CO2 emissions in Malaysia: evidence from Granger causality test. Energy Procedia 105:3118–3124. https://doi.org/10.1016/j.egypro.2017.03.654
York R, Rosa EA, Dietz T (2003) STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecol Econ 46:351–365
Zafeiriou E, Azam M (2017) CO2 emissions and economic performance in EU agriculture: some evidence from Mediterranean countries. Ecol Indic 81:104–114. https://doi.org/10.1016/j.ecolind.2017.05.039
Zahringer K, Kolympiris C, Kalaitzandonakes N (2018) Time to patent at the USPTO: the case of emerging entrepreneurial firms. J Technol Transf 43:923–952. https://doi.org/10.1007/s10961-016-9524-1
Zhang Y-J, Peng Y-L, Maa C-Q, Shenc B (2017) Can environmental innovation facilitate carbon emissions reduction? Evidence from China. Energy Policy 100:18–28
Zhou Y, Liu Y (2016) Does population have a larger impact on carbon dioxide emissions than income? Evidence from a cross-regional panel analysis in China. Appl Energy 180:800–809. https://doi.org/10.1016/j.apenergy.2016.08.035
Zhou H, Sandner PG, Martinelli SL, Block JH (2016) Patents, trademarks, and their complementarity in venture capital funding. Technovation 47:14–22. https://doi.org/10.1016/j.technovation.2015.11.005