II. How are Industrial Sector Optimization, Mitigation Policies and Taxes Contributing to Carbon Neutrality? Threshold evidence from Europe

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Abstract

There is a growing interest in the significance of product and process innovations in the battle against global emissions. However, from an innovation standpoint, mitigating strategies concentrated on patents, not the role played by trademarks. As a result, we compare the effectiveness of trademarks and patents in Europe in terms of mitigating the effects of patents. Their complementary role is tested using the interaction between the patent and the trademark (INV). Similarly, the study examines the threshold effect of carbon pricing (CTAX) and environmental policies (EPLY) for a period spanning from 2001 to 2019. The outcomes reveal that product and process innovation are driving towards carbon neutrality. The evidences further suggest that if innovation is above threshold (INV> 10.5) point, 1% increase in it can lower the emission by 2.09%. Moreover, further strengthening the environmental policies and 1% increase in taxes can neutralize emission by 6.9% and

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2.93%, respectively. It is further observed that trade openness, energy consumption, economic growth and urbanization have detrimental effect on the environment. The study concludes that taxes can be used as a short run tool however, innovations in different sectors and stringent environmental policy can guide the economies towards sustainable economic growth while protecting the environment.

***Keywords*:** Innovation; Carbon Taxes; Environmental Policy; Carbon Neutrality; Threshold regression
***JEL Codes*:** Q55; H23; Q58; C24

1. Introduction

Ecological sustainability and greenhouse gas emission reduction are major worldwide concerns, just as important as the maintenance of the economic system. Over recent decades, environmental challenges have been addressed via innovation (Qiang *et al.,* 2019). As a result, most organizations abandoned short-term environmental reaction tactics and strategies in favor of proactive and creative environmental initiatives (Faraj et al. 2015). Similarly, innovation, technical developments, economic structural reforms, and environmental policies can all assist in the transformation (Duan *et al.,* 2021a). Furthermore, technological improvements, economic structural changes, and environmental legislation can all be revolutionary (Abdallh and Abugamos, 2017). Proactive industries are constantly modifying goods, manufacturing processes, and technology to create a more sustainable environment (Khurshid *et al.,* 2022a). Manufacturing techniques, production tools, systems, and new production methods are all examples of process innovation (Khurshid *et al.,* 2018).

Product innovation, on the other hand, refers to the updating of items that have the potential to considerably improve their desired use or operation (Schumpeter, 1961; Tidd *et al.,* 2005). Patent rights safeguard technological achievements, whereas trademark rights protect traders' assets (Khurshid and Deng, 2021). Patent rights safeguard technological achievements, whereas trademark covers marketing assets (Xie *et al.*, 2022). The first entity to file for a trademark receives legal protection that prevents others from using the same sign in a given market (Khan *et al.,* 2022). As social, industrial, and economic aspects are related to carbon dioxide emissions, the global economy views an eco-friendly environment as a primary driver of economic growth.

Environmental deterioration is connected to economic development since it increases energy consumption/demand, which enhances industrial capacity but damages the environment. Rural-urban mobility generally causes an increase in urban amenities such as residential, transportation, and infrastructure (Wang *et al.,* 2021). According to urban ecological transition theory, boosting urban well-being often positions industrial companies at the vanguard of decarbonization operations. Because of its interaction with industry, urbanization increases energy consumption and carbon emissions, resulting in environmental damages (Liddle, 2014). To address this externality, European governments have increasingly embraced the carbon tax policy as a short-term strategy for green development. These funds are intended to be utilized to safeguard the environment and support green technology in the future. Therefore, the purpose of this research is to identify the influence of industrial sector optimization through innovation, environmental policies, and taxes in lowering emission in selected European countries.

The economies of Western Europe are far more developed and industrialized. However, Germany, France, the Netherlands and Belgium are the worst pollutants in air and water as a result of heavy manufacturing, urbanization, transportation, and waste disposal (Khurshid and Khan, 2021). There has been substantial progress in emission reduction in recent years. Nonetheless, nitrogen oxide (NO2) concentrations are consistently over their recommended levels (Wenqi *et al.,* 2022). Meanwhile, Germany leads the Western area in terms of intellectual property rights innovation and awareness, with patents in France and trademarks in the Netherlands. Similarly, the Western area has more patents and traditional trademark registrations than the Southern region. Türkiye is the top emitter because of industrial growth and urbanization, followed by Spain, Cyprus, and Greece.

The prior research examines the impact of innovations on environmental deterioration by focusing only on relevant patents. Whereas services and the development of new products harm the environment as well, however, their contributions in empirical studies are rarely explored in detail. A trademark application takes less time than a patent application. The goal of this research is to see whether the link between innovation, carbon prices, and environmental legislation has an asymmetric effect on ecological degradation using panel threshold regression. The research examines the link between innovation and emissions by adding trademarks and patents to determine how much each may decrease carbon dioxide emissions. Second, we use the interaction term, which denotes the coupling of trademarks and patents that represents total innovation. We're also investigating how these two types of intellectual property may help with climate mitigation. Third, key threshold factors such as carbon tax and policies were picked to provide insight into how to present regulations to assist economic development and environmental conservation of Europe.

The remainder of the paper is organized in the following manner. The paper's second half covers related literature, while the third piece concentrates on data and the technique used to evaluate the study's premise. The findings are discussed in the fourth part, and the fifth portion closes with implications.

2. Literature Review

The previous literature has gone into great detail on the critical role that ecological advancements may play in pollutant management and environmental protection. The present section summarizes significant material on trademarks, green patents, urbanization, carbon taxes, environmental policies, and energy use as they relate to CO2 emissions.

The idea that many factors, such as population and technology, may influence the environment was expressed by (Duan *et al.,* 2022). Some academics describe how technology may help limit Carbon footprints while respecting the environment. For OECD nations, Khurshid and Khan (2021) and Mensah *et al.*, (2018) showed the reverse. They discovered that a refusal to surrender patent rights had the opposite effect. Technologies have been developed by industries, corporations, and people to meet a variety of requirements, including pollution. Environmental innovation encompasses not just technology but also all other things that aim to make the world a better place. Albino *et al.* (2014) argued that newly developed pollution-reduction methods should be protected by patents. According to Sua and Moanibab (2017), a country's patents connected to climate change technology are linked to its CO2 and other greenhouse gas emissions. Khurshid *et al.* (2022b) looked at how brands have been used to quantify innovation, with a focus on product innovation. The optimal natural approach for technological development or product innovation, according to Flikkema *et al.* (2019), is to create brands. Khan *et al.* (2018) demonstrated that trademarks serve two purposes: identifying particular products and services from their source and distinguishing themselves from competitors in the same sector. Furthermore, according to Block *et al.* (2014), it is the brand that offers new companies a competitive advantage by providing protection and producing value goods. According to Zhang *et al.* (2021), market innovation opens the door to success and environmental protection by allowing a firm to differentiate itself technologically and from its competitors. A company's brand is a representation of its marketing and technological strengths. Mendonça *et al.* (2004) noted that, like patents, trademarks are used to assess a company's innovative strategies. Patents may also be used as an additional source of data to give information on current development in the subject (Mendonca *et al.,* 2004; Patel and Vega, 1999). The significance of the brand in emissions was not taken into consideration in the empirical research on the relationship between innovation and emissions. Trademarks and patents, on the other hand, may help to reduce carbon emissions. As a result, the current research attempts to close this gap by examining the influence of patents and trade-mark on pollution reduction.

Environmental innovations must be implemented to reduce emissions. Choosing the correct channel to apply innovation may increase performance in a variety of areas, including pollution control. Marsillac and Roh (2014) demonstrated that product and process innovation are mutually exclusive. The endeavor to modify the product must enhance the manufacturing process as well as the channel through which it is implemented. Empirical research has found many ways wherein innovation might impact emissions. Labor and capital productivity may be increased via innovation. It may also hasten technical progress, increasing efficiency by making better use of limited resources. As a result, industries, firms, and employees must get acquainted with new technologies as they emerge. Employees must be educated on the health advantages of high-tech innovation. Furthermore, new environmental technologies will be used in the production and manufacturing chains. After effective implementation by its personnel, a company's, industry's, or organization's innovation may be transmitted to other firms that harm the environment. Services and product innovation should be prioritized by the Ministries. Not only will this increase production and growth, but it will also cut carbon emissions. It will boost production and growth while simultaneously lowering emissions. R&D and advertising may tell customers about the environmental benefits of their goods and services. By lowering the influence on the environment, the company can also promote its brand and the goods and services it produces.

According to Mikayilov *et al*. (2018), rural-urban migration leads to economic development, which raises power consumption, and uplifts emissions. Meanwhile, Song *et al.* (2018) show that in today's world, urbanization promotes economic development. Chang (2010) demonstrated that migration from rural to urban regions boosted demand for infrastructure and resulted in town growth. This has resulted in a higher need for products and services, as well as increased energy consumption among residential and business customers. According to Xie，Fang and Liu (2017), the requirement for transportation and the rise of that industry is linked to CO2 emissions. According to Wang *et al.* (2021), urbanization is boosting ecological impact. According to Burton (2000), to

protect cities from these threats, we must construct green cities that regulate pollution by reducing the efficient use of resources. Green urban architecture design is predicted to be implemented in densely populated cities for carbon reduction, according to (Xuan *et al.,* 2021). Murad et al. (2019) urge that Denmark develop a smart energy plan that utilizes innovations and energy pricing for energy security and pollution reduction. Carbon emissions may be restricted by rigorous government policies and carbon taxes, according to Duan *et al.* (2021b). However, environmental laws must restrict tax payments to a certain level, since decarburization would be hindered if it is totally dependent on carbon taxes (Khurshid and Deng, 2021). According to Wang et al. (2017), the good and bad elements of urbanization are inextricably linked. Behind the growth in CO2 emissions are issues connected to increased demand and energy use. These researches spanned a wide range of areas and nations at varying levels of industrialization, and the findings contradicted one another. There is no agreement on the results or the exact link between urbanization and CO2 emissions. This paradox and these inconsistencies drive us to investigate this connection in order to contribute to the field.

3. Data and Methodology

The association between CO2, Innovations (INV), trademarks, patents (PET), carbon price (CTAX), and environmental policy (EP) is investigated in a panel of selected European countries. The selection of countries was based on the consistency and availability of the data. The study spanned from 2000 to 2019. The European states under consideration include Germany [DEU], Czech Republic (CZE), Austria (AUT), Croatia [HRV], Estonia [EST], Hungary [HUN], Lithuania [LTU], Luxembourg [LUX], Latvia [LVA], Romania (ROU), Slovak Republic [SVK], Switzerland [CHE], Slovenia [SVN] and Poland [POL]. The data set is collected from IEA statistics, OECD, and world bank data sources. Table 1 illustrates a list of variables and a summary of the data's descriptive analysis.

Table 1.

Descriptive analysis

Variable Name	Description	Unit	Mean	Std. Dev.	Skewness	Kurtosis
Carbon Emission	CO_2	Million Tonnes	123.44	223.72	2.60	8.57
Environmental Policy	EPLY	Index	1.90	0.96	-0.21	1.61
Carbon Taxes	CTAX	Billion $	8.63	17.84	3.08	11.23
GDP per capita	GDPC	1000 $	28.05	26.77	1.77	5.42
Urbanization	URB	Million	9.41	16.45	2.61	8.61
Trade Openness	TOPN	Billion $	363.55	679.60	3.20	12.72
Energy Consumption	ECON	Million Tonnes	46.42	84.11	2.78	9.46
Patent	PET	Number 1000	5.94	16.37	3.15	11.05
Trademark	TMRK	Number 1000	22.40	30.70	2.10	6.71
Innovation	INV	Number 1000	380.13	1250.94	3.25	11.78

3.1. Methodology

The threshold regression technique outlined by Hansen (1999) is used to describe the structural break threshold and divide the observations into various regimes with fixed effects. It may either exceed or fall below the threshold amount. The INV, EPLY and CTAX are chosen as a threshold variables, and the single threshold regression of the equations is estimated as follows:

$$CO_{2it} = \begin{cases} \alpha_i + \beta_1 INV_{it} + \rho^* x_{it} + \epsilon_{it}, & if\ INV\ is\ \leq \theta \\ \alpha_i + \beta_2 INV_{it} + \rho^* x_{it} + \epsilon_{it}, & if\ INV\ is\ > \theta \end{cases}$$

$$\rho = (\rho_1, \rho_2, \rho_3)^* x_{it} = (CTAX_{it}, TOPN_{it}, ECON_{it}, GDPC_{it}, URB_{it}) \quad (1)$$

where CO_{2it} is the dependent, INV_{it} is independent and threshold variable. x_{it} is the representation of control variables that effect the CO_{2it}. The control variables includes, carbon taxes ($CTAX_{it}$), trade oppnness ($TOPN_{it}$), energy consumption ($ECON_{it}$), gross domestic product ($GDPC_{it}$) and urbanization (URB_{it}) as suggested by the Khurshid *et al.* (2022c). α_i is the fixed effect whereas, θ is the represent threshold, β are the variables cofficient. $\rho = (\rho_1, \rho_2, \rho_3)^*$ are the cofficients of control variable and $\in_{it}$ is the error term.

$$CO_{2it} = \begin{cases} \alpha_i + \beta_1 EPLY_{it} + \rho^* x_{it} + \in_{it}, & if\ EPLY\ is\ \le \theta \\ \alpha_i + \beta_2 EPLY_{it} + \rho^* x_{it} + \in_{it}, & if\ EPLY\ is\ > \theta \end{cases}$$

$$\rho = (\rho_1, \rho_2, \rho_3)^* x_{it} = (PET_{it}, TMRK_{it}, TOPN_{it}, ECON_{it}, GDPC_{it} + URB_{it}) \tag{2}$$

$$CO_{2it} = \begin{cases} \alpha_i + \beta_1 CTAX_{it} + \rho^* x_{it} + \in_{it}, & if\ CTAX\ is\ \le \theta \\ \alpha_i + \beta_2 CTAX_{it} + \rho^* x_{it} + \in_{it}, & if\ CTAX\ is\ > \theta \end{cases}$$

$$\rho = (\rho_1, \rho_2, \rho_3)^* x_{it} = (PET_{it}, TMRK_{it}, TOPN_{it}, ECON_{it}, GDPC_{it} + URB_{it}) \tag{3}$$

whereas, $EPLY_{it}$ and $CTAX_{it}$ are the threshold variables in the model 2 and 3. The control cariables in these models includes patents (PET_{it}), trademark ($TMRK_{it}$), trade oppness ($TOPN_{it}$), energy consumption ($ECON_{it}$), gross domestic product ($GDPC_{it}$) and urbanization (URB_{it}).

Model 1, 2 and 3 is rearranged into equation 4, 5, and 6 respectively.

$$CO_{2it} = \alpha_{it} + \beta_1\, INV_{it} I\,(INV \le \gamma) + \beta_1\, INV_{it} I\,(INV > \gamma) + \rho^* x_{it} + \in_{it} \tag{4}$$

$$CO_{2it} = \alpha_{it} + \beta_1\, EPLY_{it} I\,(EPLY \le \gamma) + \beta_1\, EPLY_{it} I\,(EPLY > \gamma) + \rho^* x_{it} + \in_{it} \tag{5}$$

$$CO_{2it} = \alpha_{it} + \beta_1\, CTAX_{it} I\,(CTAX \le \gamma) + \beta_1\, CTAX_{it} I\,(CTAX > \gamma) + \rho^* x_{it} + \in_{it} \tag{6}$$

Where *I* is the indicator function.

For double threshold regression, the system is written in the following way.

$$CO_{2it} = \begin{cases} \alpha_{it} + \beta_1\, INV_{it} + \rho^*\, x_{it}, & if\ INV \le \gamma \\ \alpha_{it} + \beta_2\, INV_{it} + \rho^*\, x_{it} + \in_{it}, & if\ \gamma_1 < INV \le \gamma_2 \\ \alpha_{it} + \beta_2\, INV_{it} + \rho^*\, x_{it} + \in_{it}, & if\ INV \le \gamma_2 \end{cases} \tag{7}$$

$$CO_{2it} = \begin{cases} \alpha_{it} + \beta_1\, EPLY_{it} + \rho^*\, x_{it}, & if\ EPLY \le \gamma \\ \alpha_{it} + \beta_2\, EPLY_{it} + \rho^*\, x_{it} + \in_{it}, & if\ \gamma_1 < EPLY \le \gamma_2 \\ \alpha_{it} + \beta_2\, EPLY_{it} + \rho^*\, x_{it} + \in_{it}, & if\ EPLY \le \gamma_2 \end{cases} \tag{8}$$

$$CO_{2it} = \begin{cases} \alpha_{it} + \beta_1\, CTAX_{it} + \rho^*\, x_{it}, & if\ CTAX \le \gamma \\ \alpha_{it} + \beta_2\, CTAX_{it} + \rho^*\, x_{it} + \in_{it}, & if\ \gamma_1 < CTAX \le \gamma_2 \\ \alpha_{it} + \beta_2\, CTAX_{it} + \rho^*\, x_{it} + \in_{it}, & if\ CTAX \le \gamma_2 \end{cases} \tag{9}$$

There are various benefits of using the panel threshold approach over standard nonlinear procedures. First, it may make varied linkages in the type of sign and magnitude accessible, which might trigger the heterogeneity issue. It investigates the link between and among variables under various regimes. Second, the nonlinear equation does not need the threshold effects and is derived from endogenously driven sample data (Pan et al., 2016). Third, the less well-fitting approach for evaluating the asymmetric connection is unable to catch acute turning points. Nevertheless, the panel threshold approaches can identify turning spots (Kourtelos *et al.,* 2016). Finally, the approach may investigate further sample splits as well as fixed effects to find co-movement produced by exogenous shocks (Asimakopoulos and Karavias, 2016).

4. Results and Discussion

To solve the problem of spurious regression, the panel threshold regression requires the stationarity test of all variables. Table 2 displays the panel unit root test findings, which indicate that all variables are stable and that the panel threshold model is adequate for estimating INV, EPLY, and CTAX impact on the CO2.

Table 2

Panel Pesaran CADF-CIPS unit root tests

	Pesaran's CADF test		Pesaran Panel Unit Root Test with cross-sectional (CIPS)	
Variables	*t*-statistic	*p*-value	*t*-statistic	*p-value*
CO_2	-3.101***	0.000	-3.804***	0.000
EPLY	-2.534***	0.000	-4.388***	0.000
CTAX	-2.482***	0.000	-4.015***	0.000
GDPC	-2.786***	0.000	-3.158***	0.000
URB	-2.190***	0.003	2.750***	0.000
TOPN	-2.481***	0.014	-2.944***	0.000
ECON	-3.159***	0.000	-3.838***	0.000
PET	-3.639***	0.000	-3.830***	0.000
TMRK	-2.579***	0.002	-3.365***	0.000
INV	-3.051***	0.000	-3.539***	0.000

Note: ***, **, and * shows significance at the 1%, 5% and 10%, respectively.

4.1. Innovation and CO_2

The bootstrap technique is used to calculate the F-statistics, and the threshold effect results are shown in Table 3. It shows that the F-statistics of the single threshold are 46.165 times bigger than the 1 percent critical value of 42.117. It validates the single criterion with a significant value of 10.5. The single threshold effect illustrates the importance of INV in the CO_2.

Table 3

Threshold effect of INV on CO_2

Test	Threshold Estimates	F-statistics	Bootstrap *p*-value	Bootstrap Critical values		
Single threshold	10.5	46.165***	0.000	26.540	31.414	42.117
Second threshold	12.09	8.323	0.630	21.293	29.404	41.854
	10.5					
Triple threshold	5.465	4.354	0.610	13.056	19.186	23.988
	18.09					
	10.5					

*Note: *** at 1% significance*

The projected threshold value of θ = 10.5 serve as diving point as summarized in Table 4. It shows that when INV is lower than threshold value (10.5) the calculated value of $\hat{\beta}_1$ will be -1.896 and heterogeneous and homogenous standard errors are both significant also. The results signify that 1% upsurge in the innovation can lower 1.896% carbon emission in the sampled countries. The outcomes are in line with the findings of (Khurshid and Khan, 2021) who find similar relationship in the emerging countries. Similarly, when INV is above the threshold (INV> 10.5) the estimated $\hat{\beta}_2$ will be -2.099. This shows negative-significant influence of INV on CO2. This implies that 1% rise in the innovation can neutralize the emission by the -2.099. As innovations uplifts the sophistication in the product and process innovation which lower the inputs, reduces energy consumption and help in the mitigation process **(OWN PAPER**).

Table 4

Estimated coefficients of Innovation

Table 4	Coefficients	OLS_{se}	t_{OLS}	White se	t_{White}
$\hat{\beta}_1$	-1.896	1.077	-1.761*	1.128	-1.680*
$\boldsymbol{\hat{\beta}_2}$	**-2.099**	**1.050**	**-1.999****	**1.159**	**-1.812***

Notes: 1. White se (OLS se) is abbreviation for heterogeneous (homogeneous) standard errors.
2. β_1 (β_2) implies that the estimated coefficients are less (more) than the threshold value.
*3. * and ** specify significance 1% and 5 % level.*

The study used the control variables namely; carbon taxes, trade openness, energy consumption, gross domestic product and urbanization to estimate their impact on the carbon emission. The results are summarized in the Table 5. The outcomes show that CTAX $\hat{\rho}_1$ have negative but signifcent impact on carbon emission. It means that increase in the carbon taxes can help in neutralizing the emission in Europe. However, the sign and coefficient values of trade oppnness $\hat{\rho}_2$, energy consumption $\hat{\rho}_3$, GDP growth $\hat{\rho}_4$ and urbanization $\hat{\rho}_5$ helping in more greenhouse gas emission. The numbers further indicate that urbanization is the biggest polluter followed by the energy consumption and GDP growth. As urbanization increases infrastructure need, uplifts product demand and production, increases energy consumption which boots the economic growth it however, has detrimental effect on the environment (Khurshid et al 2022b).

Table 5

Estimated coefficients of the control variables in INV-CO_2 model

Table 4		Coefficients	OLS_{se}	t_{OLS}	$White_{se}$	t_{White}
CTAX	$\hat{\rho}_1$	-2.903	1.376	-2.110**	1.425	-2.037**
TOPN	$\hat{\rho}_2$	0.200	0.074	2.686**	0.139	1.442
ECON	$\hat{\rho}_3$	3.089	2.189	1.411	1.148	2.690
GDPC	$\hat{\rho}_4$	2.771	1.299	2.133**	1.498	1.849*
URB	$\hat{\rho}_5$	4.171	2.320	1.798*	2.010	2.075**

*Note: *, ** and *** indicates significance at the 10%, 5% and 1% level, respectively*.

4.2. Environmental Policy and CO_2 Emission

The threshold effect of environmental policy on carbon emission in the selected European countries is summarized in the Table 6. The F-statistic value indicates the presence of single threshold value that is 37.783 higher than the 1% critical vale of the 30.89. It supports the criteria and portrays the importance of environmental policies in carbon emission.

Table 6

Threshold effect of Environmental Policy on carbon emission

	Threshold Estimates	F-statistics	Bootstrap p-value	Bootstrap Critical values		
Single threshold	13.141	37.783**	0.030	18.653	20.700	30.891
Second threshold	12.54	6.166	0.480	13.215	15.639	40.762
	13.141					
Triple threshold	12.683	2.414	0.820	10.337	12.526	24.357
	12.54					
	13.141					

Note: ** at 5% significance

Table 7 sum-up the coefficient vales of EPLY ($\hat{\beta}_1$, $\hat{\beta}_2$) and control variables $\hat{\rho}_1$, $\hat{\rho}_2$, $\hat{\rho}_3$, $\hat{\rho}_4$, $\hat{\rho}_5$ and $\hat{\rho}_6$ are representing the control variable namely patents, trade mark, trade openness, energy consumption, GDP and urbanization. The results shows that if the threshold value is 13.14 than the estimated coefficient values $\hat{\beta}_1$will be -8.655 with both standard errors will be significant as well. It indicates that 1% strengthening the environmental policies can lower the emission by -8.65%. similarly, when EPLY > 13.14, the estimated value of $\hat{\beta}_2$will be -6.93%, signifying that current policy stagnancy is helping Europe towards neutralizing the negative effect of this externality.

The negative sign of the coefficients ($\hat{\rho}_1$, $\hat{\rho}_2$) of variables such as patents and trade mark are helping in lowering the emission. Where more dominant effect is observed in the case of patents. However, the estimated values of $\hat{\rho}_3$, $\hat{\rho}_4$, $\hat{\rho}_5$ and $\hat{\rho}_6$ representing trade openness, energy consumption, GDP and urbanization show that they are contributing positively in environmental degradation. The results are in line with the findings of previous model that shows that urbanization is the major culprit followed by energy consumption and economic growth.

Table 7

Estimated coefficients of Environmental policy and control variables

	Coefficients	OLS_{se}	t_{OLS}	$White_{se}$	t_{White}
$\hat{\beta}_1$	-8.655	5.145	-1.682**	4.604	-1.880*
$\hat{\beta}_2$	-6.931	4.054	-1.710**	3.115	-2.225**
$\hat{\rho}_1$	-4.067	4.943	0.823*	5.046	0.806*
$\hat{\rho}_2$	-1.298	1.096	-1.184*	0.833	-1.558*
$\hat{\rho}_3$	3.124	1.261	2.478**	1.178	2.652**
$\hat{\rho}_4$	4.996	2.548	1.961*	1.937	2.579**
$\hat{\rho}_5$	2.163	1.632	1.325*	1.265	1.711*
$\hat{\rho}_6$	7.706	11.403	0.676	6.843	1.126

*Note: 1. *, ** and *** indicates significance at the 10%, 5% and 1% level, respectively.*

2. White se (OLS se) is abbreviation for heterogeneous (homogeneous) standard errors.

3. β_1 (β_2) implies that the estimated coefficients are less (more) than the threshold value.

4.3. Carbon taxes and CO_2

Carbon taxes are considered an important tool in the mitigation process. The threshold effect of carbon taxes emission is tested and results are summarized in Table 8. The outcomes (F-statistics 44.373) show the presence of single threshold estimate (12.8) value higher than the 1% critical value. It signifies the importance of this carbon taxes-emission relationship.

If the threshold value θ = 12.80 than as per Table 9, $\hat{\beta}_1$ coefficient of CTAX will be -1.697. Whereas, if it is above 12.80 than the estimated coefficient ($\hat{\beta}_2$) value will be -2.976 with significant heterogeneous/homogeneous standard errors. It means that at 12.80 value, 1% increase in the carbon taxes can lower the emission by 1.697%. Whereas, when CTAX> 12.80 1% increase in the CTAX lower emission by 2.976%.

The coefficient values of the control variables from $\hat{\rho}_1$ - $\hat{\rho}_6$ that are influencing the CO_2 are in Table 10. The results points out that economic growth, energy consumption, urbanization and trade openness have negative effect on the environment whereas, product and process innovation in the industrial sector can contribute in promoting the environment.

Table 8

Threshold effect of Carbon Taxes on carbon emission

Test	Threshold Estimates	F-statistics	Bootstrap p-value	Critical values		
Single threshold	12.80486	44.373**	0.040	22.376	27.993	33.845
Second threshold	13.10573	2.654	0.760	13.905	15.794	30.960
	12.80486					
Triple threshold	13.30116	2.026	0.870	10.278	12.185	15.229
	13.10573					
	12.80486					

*Note: ** at 5% significance*

Table 9

Estimated coefficients of carbon taxes

	Coefficients	OLS_{se}	t_{OLS}	$White_{se}$	t_{White}
$\hat{\beta}_1$	-1.697	0.769	-2.208**	0.693	-2.451**
$\hat{\beta}_2$	-2.976	1.544	-1.927*	1.429	-2.083**

Note: 1. **, ** and *** indicates significance at the 10%, 5% and 1% level, respectively.*
2. *White se (OLS se) is abbreviation for heterogeneous (homogeneous) standard errors.*
3. *β1 (β2) implies that the estimated coefficients are less (more) than the threshold value.*

Table 10

Estimated values of control variables in CTAX-CO2 relationship

		Coefficients	**OLS_{se}**	**t_{OLS}**	**$White_{se}$**	**t_{White}**
GDPC	$\hat{\rho}_1$	1.916	1.144	1.575*	1.069	1.792*
URB	$\hat{\rho}_2$	7.111	4.245	1.675*	3.018	2.356**
TOPN	$\hat{\rho}_3$	2.146	1.081	1.986*	1.153	1.861
ECON	$\hat{\rho}_4$	3.809	2.329	1.636*	1.358	2.806**
PET	$\hat{\rho}_5$	-1.920	4.695	-0.409*	5.791	-0.332
TMRK	$\hat{\rho}_6$	-1.691	1.014	-1.668*	0.957	-1.768*

*Note: *, ** and *** indicates significance at the 10%, 5% and 1% level, respectively.*

In sum, the findings suggest that developing green technology in these countries may help them handle their pollution issues. As a consequence, the rise of such patents and trademarks has grown more noticeably which lowers the supply-side emissions in Europe due to improvements in product and process innovation. According to Thoma (2015), PEAT and TMRK are mutually beneficial, so enterprises should apply for both. This study combines both as an interaction term (INV), and the findings show that their interaction (INV) can neutralize the environmental effect of human activities.

The outcomes further show that environmental regulations in the study area significantly contribute and have a noticeable mitigating impact. The purpose of environmental policy is to design rules so that they accomplish their goals effectively rather than just meet them. Similarly, accomplishing environmental goals at the lowest possible cost while distributing the burden equally across companies and governments, and developed economies in European countries are on the point in this situation (Khurshid *et al.,* 2020). The advancement of technology contributes to the efficacy of policies in meeting aims. The recent surge of mitigation techniques, federal assistance, and industrial engagement in the innovation process are all contributing to a greener environment (Khurshid *et al.,* 2022b).

The last technique investigated the role of carbon pricing in cutting emissions. The findings imply that carbon taxes in European countries are a successful pollution-reduction strategy. It is a critical step in lowering emissions and meeting the goals of sustainable development (SDGs). Carbon levies push the industry to move away from polluting fuels and toward green ones. It will not only lower business manufacturing costs (due to taxes) but will also aid in sustainable growth (Khurshid and Deng, 2021). Carbon pricing is one approach to cutting emissions in exchange for nationally specified commitments (NDC). According to the study, the program is beneficial throughout Europe. To limit pollution, an ecological tax is required until the transformation is completed. Governments must implement state-level pricing policies and offer incentives for businesses that reduce pollution.

In contrast, the region's ecosystem is being degraded by urbanization, economic expansion, and energy use. Urbanization increases the need for basic housing and infrastructure; economic expansion boosts output and power consumption, which is mostly derived from fossil fuels and has an adverse influence on the global ecosystem.

5. Conclusion

The research aims to investigate the influence of innovation, carbon prices, and environmental policies on CO2 emission in Europe. The study tested the relationship using the panel Threshold regression approach for a period from 2001 to 2019. The results reveal that patents and trademark have significant impact in mitigation efforts. Moreover, at threshold level of 10.5, 1% upsurge in the innovation can lower 1.896% carbon emission whereas, above the threshold level 1% rise in the innovation can neutralize the emission by the -2.09%. The results further reveal that at threshold level (13.14), environmental policies can lower the emission by 8.65% whereas, above it, will limit the emission by 6.93%. In the case of carbon taxes, at 12.80 threshold value, 1% increase in the carbon taxes can lower the emission by 1.697%. whereas, when CTAX> 12.80, 1% increase in the CTAX lower emission by 2.976%. Whereas, control variables such as, GDP, trade openness, energy consumption have detrimental effect on the environment of Europe. The study provides following implications based on the results.

In order to slow down global warming, corporations and industries are developing and implementing new products, processes, technologies, and other innovations. When a patent is obtained, companies should upgrade their environmental technology and manufacturing methods so that they can get trademarks. Intellectual property (IP) will safeguard ideas and give economic incentives that motivate enterprises to take advantage of new pollution-reducing goods or services and contribute to a cleaner society.

Companies that pollute the environment should pay a hefty price in taxes, while industries that use renewables and technology should be given incentives in the form of lower taxes. Eco-taxes may have a significant role in this context. Polluting sectors would have to be substantially taxed, and companies would have to be incentivized to convert to renewables and technologies as an opportunity enforced by a low tax rate in order to reduce emissions.

Renewable technology imports should be taxed at a lower rate to encourage private investment, and regulations should support this. It will increase the share of renewable energy in the national energy mix. It is possible to lessen the negative consequences of energy usage in agriculture by switching to solar energy sources. Aside from reducing the environmental burden, green farming practices may also boost income. Solar technology improvements may be made less polluting in cities with the help of government assistance and awareness.

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