CO2 and Economic Development: The Role of Regulations, Trade, Institutions, and Innovation

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CO2 and Economic Development: The Role of Regulations, Trade, Institutions, and Innovation

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Abstract: This study seeks to uncover the shape and turning points of the Environmental Kuznets Curve (EKC) by examining the various channels that define the CO2-output relationship. The EKC is an inverted U-shaped curve that demonstrates the relationship between pollution and income. CO2 pollution generated by human activities is the leading contributor to global warming. As the global economy continues to grow with developed countries experiencing high GDP levels and many countries still at low development status, policymakers must find a way to balance economic growth and subsequent pollution. This study uses a sample of 217 countries from the World Bank Development Indicators database to examine the relationship between economic growth and pollution. Traditional EKC models are extended to include measures of trade, innovation, and regulation using fixed effects models. Fixed effects OLS regression results and calculated turning points of these models can reveal important insights into the CO2-GDP relationship, specifically relative levels of the size effect, income effect, and composition effects. Results find the existence of an inverted U-shaped EKC and a composition effect for trade variables, income effect for innovation variables through efficiency-enhancing effects of innovation, and income effect for regulation variables.

1. Introduction

The Environmental Kuznets Curve (EKC) is a widely used framework to examine the link between economic growth and environmental pollution and reveals the sustainability of economic growth. Figure 1 shows the Environmental Kuznets Curve (EKC), which is an inverted U-shaped curve graphing the relationship between environmental degradation (measured through CO2 per capita) and income (measured by GDP per capita). The EKC hypothesis, originally introduced by Grossman and Krueger (1991), posits that there is an inverted U-shaped relationship when considering economic channels through which a country's environmental quality is related to its economic development. The objective of this study is to assess the role of trade, regulation, and innovation on the EKC curvature and turning point to examine whether and how these factors influence the GDP-CO2 relationship. The basic EKC models CO2 as a function of GDP and its square. The inverted U-shape is explained through economic theory, namely the influences of the size effect, composition effect, and income effects (Pugel 2020; Grossman and Krueger 1995). These three effects are all at play and considering the dominant effect determines the shape of the relationship between GDP and CO2.

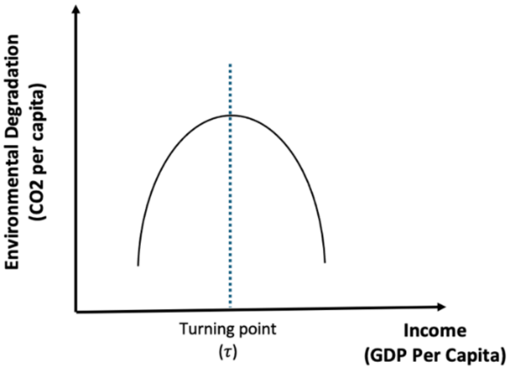

Figure 1: Environmental Kuznets Curve (EKC)

The size effect captures greater pollution implied by higher GDP resulting from increased production and consumption activities (Stern 2004; Pugel 2024). When the size effect dominates, increased GDP is associated with increased pollution levels.

The income effect captures the channel through which increased economic output can allow wealthier nations to prioritize enhanced economic standards, leading their governments to harness increased fiscal resources (Stern 2004; Pugel 2024). Consequently, these governments can afford to allocate substantial funds towards regulation and enforcement and the development and adoption of advanced technologies aimed at mitigating environmental degradation. Therefore the income effect is always negative: higher income means lower pollution via regulation or innovation.

The composition effect recognizes the structural shift in the industries that accompany economic growth, say, moving from an agrarian-dominated economy to an industrialized economy to a service and information-sector-oriented economy. The composition effect may be positive or negative based on the relative composition of economic sectors in a country (Stern 2004; Pugel 2024). Economic growth at early development levels is characterized by a shift from agricultural to industrial production processes. Industrial production necessitates the use of new machinery, which can have polluting effects (Grossman and Krueger 1991; Cole 2004; Dedoglu and Kaya 2013; Pugel 2020). With each transition that accompanies growth, pollution will rise, then decline. Thus, the composition effect is positive at low levels of income and negative at high levels of income. Moreover, the composition effect includes the influence of the dynamics of the Pollution Haven Hypothesis (PHH) (Cole 2004). The PHH considers the role of trade when examining the association between pollution and economic growth. This is an important factor to consider given that this middle level of development tends to be associated with increases in trade openness (Cole 2004). The PHH suggests that differences in the stringency of environmental regulation across countries can lead to net differences in pollution levels among countries. This is because richer countries, which typically have more stringent environmental regulations, can afford to move the production of goods requiring machinery to poorer countries with less stringent environmental regulations. In terms of trade, PHH posits that as a country develops, it can afford to shift pollution-intensive industries to less developed nations through trade, exporting pollution, and importing manufactured goods.

All three effects exist on the EKC, but whichever is the dominant effect of any given level of income defines the shape of the GDP-pollution relationship. At the initial, upward sloping portion of the EKC, the size effect and/or the positive composition effect dominates the income effect and the negative composition effect. Past this turning point, at the downward sloping portion of the curve, the income effect and/or negative composition effect dominates a positive size effect.

Given the existence of the EKC, the turning point of the curve, or its inflection point (denoted τ) is the level of GDP per capita at which the EKC begins to become downward sloping. That is the threshold of economic growth at which CO2 emissions peak before decreasing. This turning point (τ) is calculated $\tau = \exp\,[\frac{-\beta_1}{2*\beta_2}]$. The findings of Dasgupta et al. (2002) identify seven influences through which the EKC could be shifted downward and to the left, or in other words, exhibit a lower maximum turning point after which an increase in GDP is associated with a decrease in CO2 pollution. These factors are environmental regulation, economic liberalization, pervasive informal regulation, formal regulation, pressure from market agents, better methods of environmental regulation, and better information (Dasgupta et al. 2002). Each of these factors is either the size effect, composition effect, or income effect. Figure 2 shows the conventional and revised EKC where the conventional curve exhibits a higher turning point (τ_2) compared to the revised EKC and its turning point (τ_1).

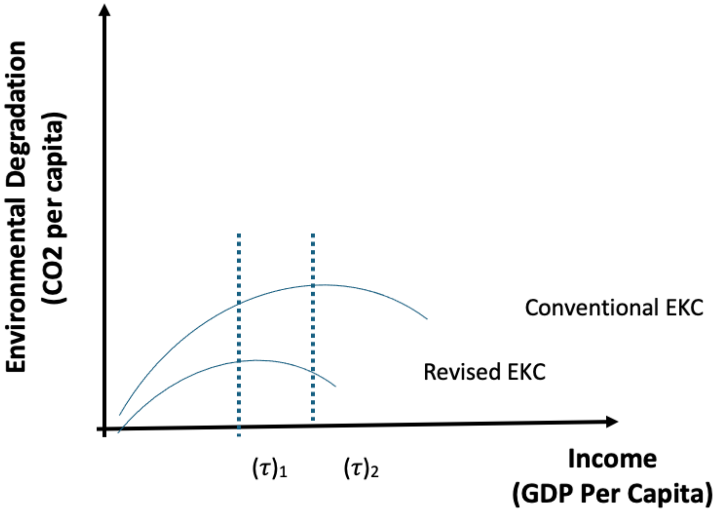

Figure 2: Conventional and Revised EKC

The EKC framework can help uncover the shape and turning points of the EKC by allowing for the examination of the impact of trade, innovation, and regulation on the GDP-CO2 relationship. In this paper, this will be done through econometric analysis of the GDP-CO2 relationship and a comparison of turning points that uncover the different channels of the size effect, income effect, and composition effects.

2. Literature Review

Findings From EKC Studies

The literature on the association between CO2 pollution and economic growth through the EKC hypothesis is vast, with most studies validating the EKC hypothesis in different countries and regions.

The EKC and its inverted U-shape has been studied and confirmed for air pollution in a majority of studies. Studies include groups of countries, individual countries, geographic regions, and from a global perspective and use different estimation methods. The inverted U-shape was confirmed in 25 OECD countries (Jebli et al. 2016), newly industrialized countries (Destek and Sarkodie 2019), European countries (Dogan and Lotz 2020), BRICS countries (Voumik 2023; Akdari et al. 2021; Rafindadi et al. 2019), and the 20 highest polluting countries (Leal and Marques 2020). The EKC hypothesis was also confirmed in a number of individual countries at various development levels, such as France (Ma et al. 2022; Iwata 2010; Shahbaz et al. 2018), the US (Alola and Ozturk 2021), Portugal, Ireland, Italy, Greece, and Spain (Balsalobre-Lorente et al. 2022), Turkey (Acaroglu et al.. 2023; Ojaghlou 2023), Australia, Belgium, Greece, New Zealand, Portugal and Turkey (Bilgili et al. 2016). A majority of studies which have considered EKC from a global perspective through including all countries in their analysis also find confirmation of the EKC hypothesis using panel data (Naves et al. 2018; Liu and Lai 2021; Harris et al. 2009; Pincheira et al. 2022). However, there are a handful of studies which find that the EKC does not hold at the global level. Results from studies in the literature ultimately vary across regions, countries, the income levels, and the chosen date ranges even only considering CO2. Studies on EKC rely on OLS estimates or the use of turning points to capture the association between pollution and economic growth. Results from existing studies ultimately vary across regions, countries, their income levels, and the chosen date ranges even only considering CO2. This study contributes to the literature by providing a global perspective on the issue of CO2 and economic growth given the validity of the PHH and the consideration of global trade dynamics and other variables that may influence this relationship. Studies on EKC rely on OLS estimates or the use of turning points to capture the association between pollution and economic growth. The use of the turning point is an important element of the literature because of its policy implications, specifically in the context of Dasgupta (2002).

The influence of different factors such as trade, innovation, and regulation on the EKC have been the focus on numerous studies which consider one or a combination of the variables. There exists rich literature on the influence of trade variables on the EKC (Cole 2002; Shahbaz et al. 2016; Aydin and Turan 2020; Pata and Caglar 2021; Ozatac et al. 2017; Koc and Bulus 2020). These studies find that considering trade openness does not impact the validity of the EKC hypothesis (Cole 2002; Pata and Caglar 2021; Sharif 2022; Ozatac et al. 2017; Suri and Chapman 1998). Moreover, considering global trade delays the turning point at which global emissions decline (Cole 2002; Jiang et al. 2019).

Further, the influence of innovation on the EKC has been studied in the literature. Moreover, studies which have used the number of patent applications found that general patenting activity is associated with an increase in CO2 (Balin and Akan 2015) which remains the case for environmental related patents (Cheng et al. 2019). Lastly, studies which have focused on the role of environmental regulation on the EKC all conclude that the influence of environmental regulation unsurprisingly acts as a main driver of improved environmental quality (Lorente and Herranz 2016; Wang 2022; Yin et al. 2015).

There is another branch of EKC literature which focuses on both the microeconomic and macroeconomic theoretical basis for the shape of the EKC. These studies first analyze the consumer optimization problem such as those conducted by Pasten and Figueroa (2012). This entails the analysis of how individual consumers make optimal choices for consumption given their income levels and preferences. By understanding these individual behaviors, researchers extend their analysis to a macroeconomic level, in which these optimal choices at the individual level are extended to countries' whole economies. The level of emissions at the country level is the result of individual optimal choices.

Other Growth-Pollution Frameworks

One other framework that has been used to understand the GDP-CO2 relationship is one that explicitly decomposes the different components or channels, through the IPAT framework. IPAT is an identify that means Impact = Population x Affluence x Technology (Chontanawat 2019; Brizga et al. 2013). For the case of CO2 emissions, it can be expressed as O2 = Pop x [GDP / Pop] x [(Energy/GDP) x (CO2 /Energy)]. It suggests that CO2 emissions are a function of the size of the population, its level of economic activity per person (affluence), and the efficiency of energy use and carbon emissions per unit of economic output (technology).

This equation reveals the interconnectedness of human activities, economic development, and environmental impact. In this formula, cancelling appropriate terms leads to CO2 as an identity, indicating that CO2 can be used as a direct measure of environmental impact. This framework can be used to extend the EKC framework to better understand its curvature by decomposing the impacts of the size effect, composition effect, and income effect channels. The affluence (A) in IPAT is directly the measure of consumption and production per capita. Analogously, GDP per capita as is the main explanatory variable in the standard EKC model.

Firstly, the size effect as outlined by Pugel (2020) aligns with the population component (P). As the population grows, there is an increase in the demand for resources and energy and consequent generation of higher pollution. The income effect corresponds to technology (T) as it focuses on the association between how higher income levels enable higher levels of innovation and more stringent regulation and enforcement, which can then yield lower environmental pollution. The composition effect can also be linked to technology (T) if structural changes in the economy or trade patterns that accompany economic growth can change the dominant energy source or pollution footprint of that energy source. Additional variables in this study's models including technological innovations, carbon tax policies, and institutions will be able to be able to capture technology (T) variables.

Contributions to Existing Literature

This study contributes to the literature by combining multiple methodologies and economic theories used in existing studies. First, this study will confirm the existence of EKC when considering all countries in a large panel dataset using OLS regression coefficients. Next, the turning points of the EKC are analyzed to see the influence of three categories of variables that influence the CO2-GDP relationship: trade, innovation, and regulation. This study contributes to the literature by providing a global perspective on the issue of CO2 and economic growth given the validity of the PHH and the consideration of global trade dynamics and other variables that may influence this relationship.

These variables were informed by both the IPAT and EKC literature, namely the variables outlined by Dasgupta (2002). The addition of individual variables to examine subsequent turning points follows the methodology of Cole et al. (2002). Lastly, the use of OLS coefficients were used to confirm the existence of the inverted U-shaped EKC and the turning points are considered to uncover the presence and strength of the size, composition, and income effects.

3. Data

Sample

This data used in this study covers 33 years (1990 – 2022) and 217 countries, analyzing EKC at the global level. This study uses World Bank Development Indicators as the source of data. The panel dataset contained economic and social indicators for each country (*i*) at time (*t*). Every country included in the original World Bank Development Indicators data was considered in this study.

A large range in dates, notably where countries are at different stages of development, could help make results more accurate than a smaller sample size and smaller range of years studied. While there were many countries represented, individual models used did not include all countries available in the data set due to missing data, which may lead to a bias in results. This is addressed using additional robustness checks which are discussed in the results section.

Variables and Descriptive Statistics

Summary statistics are displayed in Table 1. Logarithmic transformations were applied to the following variables *E*, *GDP*, *Patents*, *Researchers*, *Rdexp*¸each described in detail below. This was determined following the consult and analysis of summary statistics, existing EKC literature, and plotted data displaying a quadratic shape. This adjustment is preferable due to its alignment with the dataset characteristics and the timeframe it covers, as well as the improved interpretability it offers. It also may stabilize variances to improve the robustness of the models (Wooldridge 2019).

Table 1: Summary Statistics

Name	Variable	Obs	Mean	Std.dev.	Min	Max	Variable Notes
t	Year	7,161	2006	9.522569	1990	2022	Year
RDexp/GDP	RDEXP	7,161	0.297365	0.6959558	0	5.70555	Research and development expenditure (% of GDP)
Researchers/P	RESPerMill	1,751	2067.014	1984.405	5.86321	9081.936	Researchers in R&D (per million people)
E/P	CO2EmissionsKT	5,920	140948.7	655076.4	0	1.09E+07	CO2 emissions (kt)
E/P	CO2EmissionsT	5,920	1.41E+08	6.55E+08	0	1.09E+10	CO2 emissions (T)
Inst	CPIA	1,363	2.873074	0.6903158	1	4.5	CPIA transparency, accountability, and corruption in the public sector rating (1=low to 6=high)
IM/GDP	IMPGDP	5,645	46.29228	28.53398	0.0156225	429.3591	Imports of goods and services (% of GDP)
X/GDP	EXPGDP	5,645	40.45339	30.72466	0.0053768	433.836	Exports of goods and services (% of GDP)
P	POP	7,161	3.05E+07	1.23E+08	9182	1.42E+09	Population, total
Patents	PATENTRES	3,191	11976.93	74951.21	1	1426644	Patent applications, residents

Patents	PATENTNONRES	3,397	5464.48	23726.21	1	336340	Patent applications, nonresidents
CPricing1	CPricing1	7,161	0.0445469	0.206321	0	1	= 1 if country has a regional carbon pricing policy
CPricing2	CPricing2	7,161	0.043709	0.2044611	0	1	= 1 if country has a national carbon pricing policy
CPricing3	CPricing3	7,161	26.84234	23.8303	1	244	National carbon tax ($)
E/P	co2pop	5,920	4.240502	5.445986	0	47.65696	CO2 emissions (Tons)
Ln(E/P)	lnCO2Cap	5,900	0.5344264	1.599387	-3.826326	3.864029	CO2 emissions per capita (Tons)
Y/P	GDPCap	6,637	13269.9	21927.02	22.85037	240862.2	GDP per capita (constant LCU)
Ln(Y/P)	lnGDP	6,637	8.344123	1.63961	3.128967	12.39198	Logged GDP
Ln(Y^2/P)	lnGDP2	6,637	72.31231	27.49595	9.790437	153.5612	Logged GDP squared
Ln(IM/GDP)	lnimpgdp	5,645	3.682845	0.5695378	-4.159045	6.062294	Logged import share of GDP (%)
Ln(X/GDP)	lnexpgdp	5,645	3.474434	0.7029221	-5.225669	6.072667	Logged export share of GDP (%)
Ln(Patents)	lnpatentcap	3,132	-9.618934	1.889959	-17.08399	-3.816601	Logged patent applications per capita
Ln(Researchers)	lnrescap	1,751	6.857882	1.57562	1.768697	9.114042	Logged researchers per capita

Ln(Rdexp)	lnrdexpcap	2,237	-0.6353134	1.209073	-5.213976	1.741439	Logged R&D share of GDP (%)
Country fixed effects	countryid	7,161	109	62.64621	1	217	Country fixed effects
Year fixed effects	yrid	7,161	17	9.522569	1	33	Year fixed effects

The dependent variable in this analysis is pollution, measured in CO2 emissions in tons per capita and is represented by *E*. *E r*epresents pollution levels for a given country (*i*) at year (*t*).

The explanatory variables of interest capture measures related to economic development, trade, innovation, and regulation.

To measure a country's level of economic development, its Gross Domestic Product (*GDP*) is used. This variable is denoted as *Y* in the model. *Y* is expressed in natural log terms and adjusted for population (*P*).

To measure a country's trade activity, its import and export share of GDP is used. These variables are denoted as *IM* and *X* in the model.

Technological innovation is captured through number of patents filed, amount of researchers, and share of GDP dedicated to research and development expenditures. These variables are denoted as *Patents, Researchers,* and *RDexp.* These variables are chosen based on economic theories relating to the macroeconomic effects of innovative activities, specifically theory relating to innovation inputs and outputs. Innovation inputs are the resources that are used in the process of innovative activity and innovation outputs are the result of the innovation process. Government spending (*RDexp)* can be considered an innovation input because it is a resource that is funding innovative activity. Government spending can on research and development includes spending on four main sectors: Business expertise, government, higher education, and private non profit (World Bank Development Indicators 2024). This spending is aimed at facilitating the creation new technologies, products, and services. Similarly, the amount of productive research activity occurring in a country (captured by *Researchers*) can be considered innovation input because it is through such activities and efforts funded by government spending that innovative outputs are generated. *Patents* are considered innovation output because they are the result of the increased funding. *Patents, Researchers,* and *RDexp* are expressed in natural log terms and is are adjusted for population (*P*).

Regulation is captured through institutional quality, denoted as *Inst* and by formal regulations, captured by three crarbon pricing variables denoted as *CPricing1, CPricing2,* and *CPricing3*. *Inst* is the variable representing institutional quality, measured through the "Country Policy and Institutional Assessment (CPIA) Index". This variable serves as a proxy for the strength of institutions. CPIA is measured as a rating from 1-6, indicating indices from low to high, with higher scores generally representing more favorable conditions such as higher transparency, greater accountability, and lower corruption in the country's public sector. Institutions are the rules or norms of a country and the existence and strength of such institutions, such as strong natural resource management and stable economic markets signal a stable economy to investors and help the economy and lower pollution. *CPricing1, CPricing2, CPricing3* are the variables representing Carbon Pricing and are intended to measure the effectiveness of regulatory measures aimed at reducing carbon emissions. Carbon pricing schemes are regulatory mechanisms designed to account for greenhouse gas (GHG) emissions and can be implemented at the regional or national levels. This analysis considers carbon pricing in three ways. Dummy variables *CPricing1* and *CPricing2* capture the existence of carbon pricing policy schemes and *CPricing3* is the numeric price of carbon being taxed. The dummy variable *CPricing1* captures whether a country has a national or regional carbon pricing policy in place: it has value 1 if a country has a national or regional carbon pricing policy scheme and 0 if not. Next, the dummy variable *CPricing2* captures whether there is a national carbon pricing policy in place: it takes on the value 1 if there exists a national scheme and 0 if not. Lastly, *CPricing3* is considered for countries with national carbon pricing schemes: it is a variable representing the national price level per ton of CO2 emissions taxed under these policies. It is important to consider that the adoption and implementation of carbon pricing schemes are relatively new. Moreover, these policies have primarily been implemented in high-income countries. Out of all 95 regions and nations that had carbon pricing schemes, all but one were from high income and upper middle income countries. This may introduce some bias into the three models that include carbon pricing variables: the results for this model may only be applicable to the CO2-development relationship of upper middle and high income countries, which is discussed in the results section.

4. Methodology

Model and Hypotheses

Seven models are used to explore the per capita CO2-development relationship. Models 1A and 1B are standard models: Model 1A is linear and Model 1B is the basic EKC model which includes a quadratic term. Model 2 captures the role of trade (*IM, X*). Models 3, 4, and 5 account for innovation variables (*Patents, Reserachers, RDexp*). Model 6 and Model 7 account for regulation variables (*Inst, CPricing1, CPricing2, CPricing3*). The addition of these variables is meant to test the assertion of Dasgupta et al. (2002) that such factors can shift the EKC downward and to the left. The variables chosen for the models are correlated with GDP and are essentially embedded in the GDP variable. The use of variables correlated with GDP allows for a comparison of β_1, β_2 and thus the turning points (τ) across models. This relationship is demonstrated in the Table 2, which is a correlation matrix of variables *GDP*, *IM* , *X*, all innovation variables (*Patents, Researchers, RDexp*), and all regulation variables (*Inst, CPricing1, CPricing2, CPricing3*). Table 2 is a correlation matrix showing the correlation between the variables used. This table shows moderate and high correlation between the innovation variables and high correlation between the regulation variables. The variables for each model are also highly correlated with logged GDP with the exception of the carbon pricing variables. The correlation between logged GDP and the variables used is an essential part of this study as it confirms that they are embedded in the GDP variable. As such, models 1A through 7C include one of the innovation and regulation variables. Further, this correlation allows for comparison of turning points across models.

Table 2: Correlation matrix

	lnimpgdp	**lnexpgdp**	**lnpatentcap**	**lnGDP**	**lnrescap**	**lnrdexpcap**	**Inst**	**CPricing1**	**CPricing2**	**CPricing3**
lnimpgdp	1.000									
lnexpgdp	0.9262	1.000								
lnpatentcap	-0.0183	0.1244	1.000							
lnGDP	0.2028	0.3484	0.6018	1.000						
lnrescap	0.2235	0.3387	0.6113	0.7550	1.000					
lnrdexpcap	0.0393	0.1386	0.6167	0.6685	0.8619	1.000				
Inst	0.3678	0.1286	0.0997	0.0631	0.1109	-0.2156	1.00			
CPricing1	-0.0068	0.0246	0.1552	0.2107	0.2311	0.2317	.	1.000		
CPricing2	0.0379	0.0667	0.1377	0.2228	0.2436	0.2143	.	0.9124	1.000	
CPricing3	0.0449	0.0762	0.0949	0.2424	0.2307	0.2275	.	0.6916	0.7096	1.000

Inclusion of these factors to shift the EKC downward and leftward defined by Dasgupta et al. (2002) by capturing one of three effects: the size effect, composition effect, or income effect. These define the mechanisms through which development affects emissions (Pugel 2020). For example, in Cole et al. (2002), there is a higher turning point of GDP in models that use dirty imports and exports as additional regressors: this implies a negative composition effect embedded in the GDP variable in the basic model.

In this study, each succeeding model described in detail below, the turning points will similarly be calculated and then compared to that of the basic EKC model after adding different variables that can influence the CO2-development relationship. Models 2 through 7 expand upon the traditional EKC model by including additional variables that can serve as proxies for one of the three economic effects of interest: the composition effect (by controlling for trade through *IM* and *X*, Model 2), the innovation effect (by controlling for innovation measures such as *Patents*, *Researchers*, and *Rdexp* in Models 3, 4, and 5 respectively), and the regulation effect (by controlling for regulation variables, Model 6, Model 7A, Model 7B, Model 7C). Table 3 maps the hypothesized shifters from Dasgupta et al. (2002) to the size, composition, and income effects from Pugel (2024) and Stern (2004) with respect to the variables used in this study. The last two columns indicate the variables used in each model that test each of these potential EKC shifters.

Table 3: Relating the EKC literature to variables used in this study

Pugel (2024) and Stern (2004) effects: Channels that determine the GDP-CO2 relationship	Dasgupta et al. (2002) Revised EKC Shifters	Variables	Models
Composition effect	Economic liberalization	IM, X	Model 2
Income effect	Pervasive informal regulation	Inst	Model 6
	Formal regulation	CPricing1, CPricing2, CPricing3	Models 7A, 7B, 7C
	Pressure from market agents	CPricing1, CPricing2, CPricing3	Models 7A, 7B, 7C
	Better methods of environmental regulation	CPricing1, CPricing2, CPricing3	Models 7A, 7B, 7C
	Better information	Patents, Researchers, RDexp	Models 3, 4, 5
	Environmental Regulation	Inst, CPricing1, CPricing2, CPricing3	Models 7A, 7B, 7C

Model 1A is the linear EKC model demonstrating the impact of output (Y) and on emissions (E) with intercept (α_i), and its error term (ε_{it}). Model 1B is the basic EKC model. It demonstrates the impact of output (Y) and its square (Y^2) on emissions (E), with intercept (α_i), and its error term ($\varepsilon_{\mathrm{it}}$).

Model 1A: $E = \alpha_i + \beta_1 Y_{it} + \varepsilon_{it}$ (1A)

Model 1B: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 {Y^2}_{it} + \varepsilon_{it}$ (1B)

The significance of the coefficients for both the linear and quadratic terms will indicate whether there is in fact an inverted U-shaped relationship between CO2 and development.

Maximizing this function by taking its derivative with respect to GDP yields the value of GDP where emissions (E) is maximum: this value can also be calculated as $\tau = \exp\,[\frac{-\beta_1}{2*\beta_2}]$. The parameter estimates from the regression essentially determine the nature and extent of the CO2-development relationship as captured by the turning point of the curve.

The first extension of the basic EKC model includes trade variables, which is based on the work of Cole et al. (2002) to determine how trade affects the pollution-economic growth relationship. This equation is shown in Model 2.

Model 2: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 Y^2{}_{it} + \beta_3 IM_{it} + \beta_4 X_{it} + \varepsilon_{it}$ (2)

Similar to Cole et al. (2002), the inclusion of trade variables (*IM* and *X*) in Model 2 is expected to alter the turning point of the EKC. This change aims to uncover the composition effect, ultimately affecting the turning point of the EKC. The shift right in the turning point after the inclusion of trade variables implies that the industrial composition or trade pattern embedded in the GDP variable is one where cleaner domestic activity, higher imports and lower exports accompany economic growth. Including the trade variables disentangles the composition of domestic industries and trade pattern from GDP, thereby altering the profile of CO2 emissions. This adjustment serves to test the validity of the Pollution Haven Hypothesis (PHH). Considering trade variables separates the impact of economic growth in the GDP variable from trade influence, hastening or delaying the point at which further economic growth development significantly reduces pollution and changing the expected turning point to a lower or higher GDP level. Further, if the PHH holds, then there is expected to be a negative coefficient on the imports variable, and positive coefficient on exports: higher imports are associated with lower CO2 emissions and higher exports are associated with higher pollution.

Thus, this model's integration of trade variables, composition effect, and PHH better explains the dynamics of the CO2-GDP relationship compared to the initial model.

The next extension includes innovation measures to determine the impact of innovation on the pollution-output relationship. Based on the theoretical framework introduced by Dasgupta (2002), as economies grow and become more innovative, the point at which they start reducing pollution could occur at a lower level of economic development. But more innovation can also mean higher productivity, and hence, higher production and consumption and higher emissions. Thus, measures of innovation or innovative capacity can capture both size effect and income effect channels. That is, with the inclusion of measures of innovation, the turning point of the EKC may decrease or increase. Models 3, 4 and 5 each includes a different measure of innovative capacity: *Patents*, *Researchers* and *Rdexp*, respectively. The new variables are added one at a time due to the high degree of correlation between them.

Model 3: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 Y^2{}_{it} + \beta_3 Patents_{it} + \varepsilon_{it}$ (3)

Model 4: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 Y^2{}_{it} + \beta_3 Researchers_{it} + \varepsilon_{it}$ (4)

Model 5: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 Y^2{}_{it} + \beta_3 Rdexp_{it} + \varepsilon_{it}$ (5)

The sign of the β_3 variable is critical in this analysis. If the coefficient is positive, then the size effect of innovation dominates, indicating that higher R&D translates to net higher productivity and greater economic activity. If negative, it likely is capturing the income effect implying that higher levels of research and development catalyzes the development of cleaner production methods and technologies leading to lower pollution to offset the productivity enhancing effects. Just like Model 2, inclusion of another regressor can alter the values of β_1 and β_2, which can alter the GDP turning point. Leaving out these variables in previous models

(Model 1 and Model 2) likely leads to bias in the turning point of β_3. Thus, excluding important variables such as technological innovation or research and development efforts may present an incomplete picture of the factors impacting the GDP-CO2 relationship.

The last set of extensions involve the inclusion of both institutional and regulation variables, following Dasgupta et al. (2002) who suggest the influence of regulatory capability and improved institutional governance in confronting environmental challenges. Models 6 and Model 7A through 7C include variables pertaining to institutional quality (*Inst*) and regulation (*CPricing1-3*), respectively:

Model 6: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 {Y^2}_{it} + \beta_3 Inst_{it} + \varepsilon_{it}$ (6)

Model 7A: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 {Y^2}_{it} + \beta_3 CPricing1_{it} + \varepsilon_{it}$ (7A)

Model 7B: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 {Y^2}_{it} + \beta_3 CPricing2_{it} + \varepsilon_{it}$ (7B)

Model 7C: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 {Y^2}_{it} + \beta_3 CPricing3_{it} + \varepsilon_{it}$ (7C)

Institutions and carbon pricing policies are proxies for regulation. Although these are not traditional regulation variables, theories such as the induced innovation hypothesis and Porter Hypothesis propose that more regulation can boost innovation. These hypotheses suggest that more developed countries might improve their ability to balance economic growth and environmental impact, capturing the income effect. Stronger public institutions could be expected to facilitate pollution reduction as an economy grows and thus, inclusion of *Inst* will alter the magnitudes of β_1 and β_2. Similarly, strong regulations captured by each of the three carbon pricing variables, tend to exist in high income countries. Their inclusion will be expected to yield different β_1 and β_2 coefficients implies Both institutions and regulation capture the income effect: a more developed country could be expected to have better environmental quality because of more monitoring from having more resources and better institutions to guarantee enforcement.

Model 8 serves as a full regression model: it considers the impact of trade variables, *Patents,* and *CPricing2*. These variables were chosen because their coefficients were found to be statistically significant in regression results. Due to the correlation among the innovation variables and regulation variables, only one innovation and one regulation variable is included in Model 8.

Model 8: $E = \alpha_i + \beta_1 Y_{it} + \beta_2 Y^2{}_{it} + \beta_3 IM_{it} + \beta_4 X_{it} + \beta_5 Patents_{it} + \beta_6 CPricing2_{it}\ \varepsilon_{it}$ (8)

Through the model described above, this study explores the impact of trade, technological innovation, institutional quality and regulation on the EKC. Different turning points can verify the existence and relative strength of the size, income and composition effects of the GDP-CO2 relationship. The null hypothesis, proposing an unchanged turning point in the EKC despite shifts in economic structure, innovation, and institutional quality. If the turning point, τ, is the same across all models, then there is no evidence to support the assertions of Dasgupta et al. (2002) about the efficacy of the seven factors which make the EKC shift downward and to the left. As an alternative hypothesis, this study asserts that shifts in trade patterns, technological advancements, and institutional frameworks are likely to contribute a downward and leftward shift in the inflection point of the EKC.

Econometric Issues

This analysis must consider potential cases of heteroskedasticity and unobserved heterogeneity. Diverse economic, environmental, and social contexts are represented in the dataset, which creates the potential for heteroskedasticity, indicating unequal variance across observations. Regressions run on uncorrected models do not account for the varying spread of errors, leading to biased ordinary least squares estimates. Robust standard errors are employed in each model to address this issue.

Moreover, it is essential to account for unobserved heterogeneity across countries, which encompasses time-invariant characteristics differing among countries but remaining constant over time. These characteristics may include institutions, social or cultural norms, and geographic differences. To address this unobserved heterogeneity, the models incorporate country and year fixed effects, ensuring that factors such as institutions, social or cultural norms, and geographic disparities, which remain constant across time within each country, are appropriately controlled for.

The error term, ε_{it}, in all models contains various components: it includes a time invariant component, η_i, representing unchanging characteristics across countries, a time fixed effects component (δ_t) capturing factors that do not vary across countries but may change over time, and a component, (ϵ_{it}), that varies across both countries (*i*) and time (*t*).

5. Results

The results section analyzes regression results and calculated turning points with respect to predicted hypotheses and economic theory.

Table 4 presents regression results for all seven models. Across Models 1B through 6, both the *lnGDP* and *lnGDP2* variables consistently demonstrate statistical significance the 1% level. Importantly, the magnitudes of the coefficients for the linear and quadratic terms remain stable across models, indicating robustness in the relationship. The *lnGDP* coefficients consistently exhibit positive values, while the *lnGDP2* coefficients consistently display negative values, supporting evidence of the models adhering to the inverted U-shaped curve pattern. Moreover, while the significance of both linear and quadratic terms is consistently observed at the 1% level across models, the implied turning point of GDP varies as expected. Each model reveals a different mechanism through which CO2 relates to GDP.

Model 1A represents a regression which considers GDP as a linear term. This model is reported to serve as a comparison for Model 1B which is the basic EKC model and solely considers GDP its squared value, assuming that these are the only factors affecting pollution. Trade patterns, innovative capacity, institutions, and regulation in the form of carbon pricing are embedded in the GDP variable and also change with GDP. These effect of these factors will be disentangled from GDP in subsequent models. The turning point of the EKC curve in Model 1B is a GDP of $24,702. This turning point signifies the GDP level at which the model begins to exhibit a downward trend in CO2 emissions. Approximately 7.3% observations in the sample fall at or above this GDP across all countries and years considered. The coefficient of the quadratic term (*lnGDP2*) in Model 1B is statistically significant to the 1% level, and the linear term (*lnGDP*) remains statistically significant at 1%. These results confirm the existence of the inverted U-shaped curve.

Next, Model 2 is used to incorporate trade variables into model 1B. Model 2 was used to dissociate global trade patterns (*lnimpgdp* and *lnexpgdp*) from GDP and determine if the composition effect dominates the size and income effects. The *lnimpgdp* variable is negative and statistically significant at the 1% level and the *lnexpgdp* variable is positive and is also statistically significant at the 1% level. The τ value for Model 1B is higher than τ for Model 2 (\$15,324): as GDP grows, trade pattern is such that exports are growing more than imports, generating higher levels of CO2 in the process. Thus, countries could potentially reduce CO2 emissions even at lower levels of GDP. This result is in stark contrast to the findings of Cole et al. (2002) because of the differences in variables chosen: Cole et al. (2002) used only dirty exports and dirty imports to test whether PHH can be inferred from the EKC model. Cole et al. (2002) asserts that a higher turning point of GDP in models that include dirty imports and dirty exports are indicative of how on average, the pattern of trade in *dirty* goods associated with economic growth is one that is characterized by the shifting of production, hence pollution, away from the domestic economies, causing a lower turning point in GDP when dirty trade pattern is not dissociated from GDP.

Regression results for Models 3 through 5 demonstrate the role of innovative activity and test the existence of both the size and income effects of innovation which tends to move in tandem with GDP. All three innovation coefficients (*Patents, Researchers*, and *Rdexp*) are statistically significant and positive. A 1% increase in the number of patents filed per capita is associated with a 0.126% increase in CO2, after controlling for GDP. A 1% increase in the number of researchers per capita is associated with a 0.1% increase in CO2. A 1% increase in research and development expenditure is associated with a 0.043% increase in CO2. That higher levels of innovative activity correspond to higher pollution suggest that innovation has productivity-enhancing effects, i.e., the size effect. However, that the calculated GDP turning point for these three models are higher than that implied by Model 1B: $34,847, $43,885, and $38,569 respectively. The lower turning point in Model 1B implies that the higher innovative potential embedded in GDP causes the positive relationship between GDP and CO2 to persist only at low to moderate levels of GDP, which suggests an efficiency-enhancing effect of innovation that accompanies GDP. That is, CO2 starts to decline with economic growth at lower levels of GDP in Model 1B because innovation allows decoupling of CO2 with GDP. In sum, while there is a productivity enhancing effect of innovation (as suggested by the positive and statistically significant sign of *Patents, Researchers*, and *Rdexp* coefficients), there is also an efficiency enhancing component, as suggested by the lower turning point in model 1B when innovation is embedded in the GDP variable.

Regression results from Models 6, 7A, 7B, and 7C capture the impact of regulation on the GDP-CO2 relationship and test for the existence of the income effect. The coefficient for *Inst* in Model 6 is not statistically significant. One possible explanation is that the public sector, particularly those concerned with climate policies, may not be mature enough or may face financing or budgetary constraints to facilitate economic development that balances growth with climate change considerations. Weak public institutions may prioritize other objectives over climate-related initiatives, creating broader challenges in resource allocation and policy implementation.

The coefficients for *CPricing1*, *CPricing2*, and *CPricing3* are all negative and statistically significant at the 1% level. The negative coefficients of *CPricing1*, *CPricing2*, *CPricing3* indicate that the existence of a regional or national carbon pricing scheme is associated with a decrease in emissions, as expected. For countries or regions where such schemes are implemented, emissions tend to be lower compared to those without carbon pricing policies. *CPricing3* indicates that when considering the dollar value of the tax on carbon, a $1 increase in carbon tax per ton is associated with a very modest 0.09% reduction in CO2 per capita. Multiplying this value by the actual carbon price for each country yields the estimated reduction in CO2 emissions per capita associated with a one dollar increase in the carbon tax. This value was calculated to be an estimated reduction in CO2 emissions per capita is 0.0017435 tons. Moreover, when focusing solely on data from the year 2020, the estimated reduction in CO2 emissions per capita associated with a one dollar increase in the carbon tax was found to be approximately 0.0014813 tons. This indicates a slightly lower estimated reduction compared to the overall dataset mean of 0.0017435 tons, suggesting that newer carbon pricing policies may have a marginally reduced impact on CO2 emissions per capita. Considering that mean per capita CO2 in the sample is approximately 4.24 tons, the change in per capita CO2 from a $1 increase in carbon tax is very negligible.

The turning points for Models 7A through 7C are all greater than that implied by the basic EKC, Model 1B, with turning points are $29,827, $29,591, and $27,890 respectively. Since regulation is embedded in the GDP variable in models 7A through 7C, the lower turning point of GDP in Model 1B suggests that regulation tends to increase with income and allows an economy to decouple GDP from CO2 at lower levels of income, i.e, the income effect. The inclusion of these regulation variables in Models (7A) to (7C) dissociates regulation from GDP, implying that in the basic EKC model, the downward pressure on CO2 as an economy grows (embedded in β_1 and β_2) arises only from the composition effect. The observed trend of higher turning points in models incorporating regulatory variables implies that the regulatory measures implemented as an economy grows effectively curb emissions, reinforcing the inverse relationship between economic growth and environmental degradation. This regulation is countering any polluting effects of economic growth.

Model 8 is run as the full model including GDP, its square, trade variables, *Patents,* and *CPricing2*. The coefficients for *lnGDP* and *lnGDP2* are statistically significant at the 1% level and their signs are consistent with earlier models. The coefficient for *Patents* is statistically significant at the 1% level and are positive which is similar in sign and magnitude to its coefficient from model 3. Similarly, the coefficient for *CPricing2* is negative and statistically significant to the 1% level which is similar in sign and magnitude to the coefficient calculated from model 7B. The coefficients for *lnimpgdp* and *lnexpgdp* both lose statistical significance. These results indicate that innovation and regulation may have some impact on trade patterns of a country—this impact gets masked when all controls are included at the same time. The turning point for Model 8 is \$26,747 , which is higher than the value found for model 1B where the combination of trade, innovation, and regulation are embedded in GDP in Model 1B. In Model 1B, the influence of these variables together allows countries to reduce CO2 levels at lower levels of GDP on average. In other words, the combination of the negative composition effect, (negative) income effect of innovation (net of scale effect), and (negative) income effect of regulation are all stronger than the positive size effects.

6. Robustness Check

The consideration of each explanatory variable separately in the regression models lead to variations in the set of countries included in different models. This discrepancy can arise from differences in data availability where certain variables are more commonly reported or accurately measured compared to others. As a result, data for some countries' variables may be excluded from certain models due to missing or unreliable data, particularly if they lack the necessary resources to ensure accurate reporting. Exclusions of a country's data in one or more of the models based on data availability can introduce biases and affect the generalizability of the findings, this is particularly true for countries that face data quality challenges such as those with lower income levels, which are then disproportionately underrepresented in the sample. The results of running the regressions with the additional condition that all the variables are non-missing provide insights into the robustness of the model when only considering complete observations. Thus Table 5 includes only rich countries which have full observations for all variables.

Results for the robustness check are shown in table 5. In Table 5, the number of observations for each model is the same at 1,363, about a quarter of the original largest sample from Table 4. The *Inst* variable was omitted from the robustness check, as most countries, specifically higher income and middle income countries, had missing data for this variable.

The mean GDP per capita level of the remaining 98 countries used is $20,766.74, which is higher than the mean GDP per capita level of all countries in the sample, which is $13,269.90. Therefore, the countries considered in the analysis only using complete observations are slightly more rich, on average, than the entire sample. Moreover, countries that were omitted from this set of regressions, which represent the countries that had missing observations for a given year, have a lower GDP of $11,332.43. These initial summary statistics confirm that observations with missing data are from countries of lower development. Regression results which only consider complete observations are presented in Table 5. Only considering rich countries

The differences between the two sets of regressions can provide insights into any bias observed in the original models. Importantly, the signs, significance and magnitude of the *lnGDP* and *lnGDP2* variables are similar to their coefficients in Table 5. Coefficients of innovation variables change slightly in Table 5. The coefficient on *Patents* is still positive and statistically significant to the 1% level and is slightly lower in Table 5. Table 5 shows that the calculated impact of regulation variables vary in statistical significance, magnitude and sign coefficients on carbon pricing variables. *CPricing1* remains statistically significant at 1%, *CPricing2* loses significance to a 5% level, and *Cpricing3* is not statistically significant. Moreover, the signs for *CPricing1* and *CPricing2* coefficients become positive. In other words, when only complete observations are considered, the existence of regional and national. However, this model does not account for the fact that richer countries are associated with higher levels of pollution. Further, the existence of carbon pricing policies in a country means that the and that the country is developed enough to put in place such policies. The existence of complete observations and thus the availability of data depends on strong data collection techniques, which are already associated with increased development. Lastly, results for model 8 show that the negative composition and negative income effects dominate the positive effects when embedded in GDP on average.

The τ values for the robustness check are significantly higher than the τ values of the original regression, which is expected given that the countries considered are richer and contain no missing observations*.* When considering these turning points, there are some differences that can reveal sources of bias in the original models. Table 5 shows that the turning point of models 3, 4, 5, and 7C exhibit lower values than those of model 2, as expected. However, the turning points in Table 5 show higher turning points than the original models'. These results imply that the consideration of richer countries observations leads to a difference in the direction of the change in turning points of the EKC.

7. Conclusions and Policy Implications

The main objectives of this study were to observe the relationship between CO2 and GDP through analysis of the income, composition, and size effects. Results find the existence of an inverted U-shaped EKC and a composition effect for trade variables *(IM* and *X)*, income effect for innovation variables through efficiency-enhancing effects of innovation (*Patents, Researchers, RDexp),* and income effect for regulation variables (*CPricing1, CPricing2, CPricing3*). There is no evidence that public institutions significantly change the GDP-CO2 relationship. The implications of these findings can best be discussed in the context of Dasgupta (2002) and the existing EKC literature: the variables considered can shift the EKC downward and leftward. However, the EKC is descriptive, not prescriptive tool and as such, countries need not wait until higher GDP levels to reach peak emissions countries can ensure that lower levels of CO2 are reached at earlier GDP levels through innovative and regulatory activities. Thus, the findings suggest that policymakers could adjust policy and spending decisions can be adjusted to influence trade openness, stimulate patenting activity, continue research and development stimulating expenditures and environmental policies such as carbon pricing. However, study does not recommend the trade pattern/industrial composition channel, as it does not decrease net global pollution levels but rather redistributes pollution across different countries. Instead, regulation and innovation channels are the more reasonable channels to target to improve sustainability of economic growth.

The lower τ in model 1B compared to model 3 implies that there is an efficiency-enhancing effect of innovation that the model is picking up. That is, as economic growth occurs, it stimulates innovation. Such technological advancements allow industries to produce goods and services with fewer resources and as a result, the environmental impact of economic growth may not decrease as rapidly as initially expected. Instead, the higher τ in model 3 reflects this dynamic, capturing that while innovation promotes economic growth, there may be additional dynamics in environmental sustainability management. This is also likely given that the innovation and R&D variables are not specifically capturing only environmentally friendly technologies. For example, the variable *Patents* includes all patents of a country – this measure captures general patenting and not energy or environmental innovation specific patents. Future work could still utilize general innovative activity variables such that the productivity and efficiency-enhancing effects are measured.

Findings for formal regulation variables show very modest impacts of carbon pricing policies. A higher taxation rate for carbon pricing could have more significant reductions on CO2 emissions. Further, given the recency of the implementation of carbon pricing policies, alternate measures of environmental regulation could also be considered. Another topic for future research could involve additional differentiation by income status or other factors to see the EKC for different groups within the data.

Table 4: Regression Results

	(1A)	(1B)	(2)	(3)	(4)	(5)	(6)	(7A)	(7B)	(7C)	(8)
VARIABLES	Model 1A	Model 1B	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7A	Model 7B	Model 7C	Model 8
lnGDP	0.303***	1.008***	1.040***	0.884***	1.212***	1.149***	1.538***	0.963***	0.959***	0.972***	0.920***
	(0.0237)	(0.0839)	(0.0970)	(0.0941)	(0.0919)	(0.0684)	(0.235)	(0.0853)	(0.0856)	(0.0854)	(0.103)
lnGDP2		-0.0498***	-0.0540***	-0.0422***	-0.0567***	-0.0544***	-0.0850***	-0.0468***	-0.0466***	-0.0475***	-0.0451***
		(0.00447)	(0.00509)	(0.00526)	(0.00545)	(0.00419)	(0.0159)	(0.00458)	(0.00460)	(0.00458)	(0.00586)
lnimpgdp			-0.118***								0.00181
			(0.0297)								(0.0387)
lnexpgdp			0.0769***								-0.0578
			(0.0256)								(0.0416)
lnpatentcap				0.126***							0.118***
				(0.00886)							(0.00888)
lnrescap					0.0992***						
					(0.0158)						
lnrdexpcap						0.0429***					
						(0.0135)					
Inst							-0.0236				
							(0.0305)				
CPricing1								-0.140***			
								(0.0194)			
CPricing2									-0.153***		-0.0467***
									(0.0194)		(0.0171)
CPricing3										-0.000897***	
										(0.000138)	
Constant	-3.459***	-5.981***	-5.667***	-2.364***	-6.142***	-5.222***	-7.663***	-5.828***	-5.808***	-5.833***	-2.408***
	(0.184)	(0.362)	(0.442)	(0.489)	(0.402)	(0.304)	(0.889)	(0.366)	(0.367)	(0.368)	(0.540)
Country Fixed Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
τ		24,702.11	15,324.35	34,847.47	43,884.56	38,568.79	8,535.41	29,826.75	29,591.17	27,889.5	26,747.75
Observations	5,682	5,682	4,937	2,899	1,619	2,084	1,189	5,682	5,682	5,682	2,804
R-squared	0.975	0.977	0.980	0.979	0.989	0.985	0.974	0.977	0.977	0.977	0.979

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Regression Results Robustness Check: Regression Results Considering Only Complete Observations

	(1A)	(1B)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	Model 1A	Model 1B	Model 2	Model 3	Model 4	Model 5	Model 7a	Model 7b	Model 7c	Model 8
lnGDP	0.298***	1.063***	1.062***	0.931***	1.090***	1.048***	1.077***	1.078***	1.054***	0.953***
	(0.0258)	(0.139)	(0.138)	(0.123)	(0.126)	(0.134)	(0.138)	(0.139)	(0.139)	(0.122)
lnGDP2		-0.0486***	-0.0488***	-0.0410***	-0.0501***	-0.0479***	-0.0494***	-0.0493***	-0.0481***	-0.0419***
		(0.00805)	(0.00814)	(0.00723)	(0.00746)	(0.00788)	(0.00804)	(0.00807)	(0.00808)	(0.00732)
lnimpgdp			-0.0162							-0.0230
			(0.0537)							(0.0530)
lnexpgdp			-0.00129							0.0285
			(0.0385)							(0.0391)
lnpatentcap				0.0814***						0.0819***
				(0.00948)						(0.00957)
lnrescap					0.150***					
					(0.0176)					
lnrdexpcap						0.108***				
						(0.0247)				
CPricing1							0.0517***			
							(0.0166)			
CPricing2								0.0342**		0.0359***
								(0.0146)		(0.0137)
CPricing3									-0.000105	
									(0.000108)	
Constant	-1.021***	-4.099***	-4.031***	-2.628***	-5.032***	-3.811***	-4.156***	-4.171***	-4.060***	-2.755***
	(0.253)	(0.629)	(0.627)	(0.589)	(0.549)	(0.607)	(0.628)	(0.633)	(0.632)	(0.567)
Country Fixed Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
τ		56,121.67	53,249.04	85,150.88	52,306.23	55,819.06	54,415.93	55,891.22	57,183.14	86,039.66
Observations	1,363	1,363	1,363	1,363	1,363	1,346	1,363	1,363	1,363	1,363
R-squared	0.979	0.981	0.981	0.982	0.982	0.981	0.981	0.981	0.981	0.983

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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