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Economy, Commerce, and Energy: How Do the Factors Influence Carbon Dioxide Emissions in Japan? An Application of ARDL Model

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Abstract: Carbon dioxide (CO_2) traps heat from the sun, and thereby prevents oceans from becoming frozen solid to keep the earth habitable. CO_2 emission also stimulates global warming and increases the pace of climate change. For such contradictory influences, researchers across the globe have shown interest in examining the relationship among energy, emission, trade and commerce, focusing on different regions, including the Middle East, Africa, and Southeast Asia. Investigation from a developed country perspective is understudied. Hence, this research aims at analysing how trade and commerce, urbanisation, energy consumption, and economy affect the volume of CO_2 emission in Japan. The World Bank database was used to collect data for 1960–2010. The findings suggest that the inverted U-shaped relationship between economic progress and carbon emissions follows the Environmental Kuznets Curve theorem. However, per capita energy consumption has no significant impact on emission in the long run; the trade volume does not directly affect the emission of CO_2 in Japan. Besides,

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the ratio of the urban population shows a negative impact on carbon emission in the long run.

Keywords: emission, gross domestic product, Japan, trade, urbanization

1 Introduction

Scientific evidence about the consistent incremental changes in surface and ocean temperature alone is enough to proclaim that global warming is incontrovertible. The last four decades have constantly experienced warmer temperatures compared to the preceding decade (IPCC 2021). The evidence is compelling since other indicators, like shrinking ice sheets and climate hazards, also ensure that the earth is warming (CRU 2019; NASA 2019). During the last 120 years, the global mean sea level has increased by 0.20 m (IPCC 2021) in which the emission of carbon dioxide (CO_2) has played role. CO_2 traps heat from the sun, hinders oceans from becoming frozen solid, and helps sustenance of the living things in the earth; however, at the same time, it stimulates global warming and increases the pace of climate change.

The level of CO_2 emission varies with the factors, for instance, demography, socio-economic condition, and technology (IPCC 2000). Gross domestic product (GDP) and the relative growth of a nation are associated with the volume of production and consumption. Individual, societal and national attitudes, besides production and consumption of goods and services, affect the volume of emissions, which result in environmental pollution if not properly taken care of. The Environmental Kuznets Curve (EKC) clarifies the association between the factor of environmental pollution and average individual income. Research about decoupling growth and environmental impact hence has attracted many analysts. Accordingly, numerous initiatives have been undertaken in both the global North and South to reduce carbon emission, for instance, from the industrial units.

Because of a considerable growth in the volume of international trade of goods and services in the recent decades along with the capital increase, many researchers have shown interest in examining the relationship among energy, emission, and trade, focusing on different regions (Al-mulali and Sheau-Ting 2014). Al-mulali (2012) investigated the relationship among emissions, trade, and energy consumption in the Middle East. Al-mulali and Sab (2012a) examined the relationship between emission and development in the context of Sub-Saharan Africa. Research about the nexus among energy, emission, and gross domestic product (GDP) has also been conducted in many regions, including the Middle East and North Africa (MENA) (Al-mulali 2011; Arouri et al. 2012), Association of Southeast Asian

Nations (ASEAN) (Saboori and Sulaiman 2013a), and in many countries including Bangladesh (Alam et al. 2012), China (Govindaraju and Tang 2013; Pao, Fu, and Tseng 2012), and Pakistan (Khan et al. 2013).

The contribution of financial development to environmental pollution was investigated by Boutabba (2014). Economic development is negatively associated with CO_2 emissions and energy consumption, while the financial development of a country is positively associated with the same (Li, Zhang, and Ma 2015; Shahbaz et al. 2015). Trade variables, energy use, and CO_2 emission concurrently influence each other (Al-mulali and Sheau-Ting 2014). A positive association has also been found between income growth and emissions (Shahbaz et al. 2015). A country's financial and economic development is affected by energy consumption and CO_2 emission (Al-mulali and Sab 2012b). In newly industrialised countries, trade openness positively affects CO_2 emission (Hossain 2011). Globalisation and sources of energy were investigated by Rahman and Miah (2017). Some other studies have examined the relationship between urbanisation and carbon emission in various countries; for instance, Ouyang and Lin (2017) studied about China, and Pata (2018a, 2018b) investigated about Turkey. Economic growth pushed urbanisation in the developed countries, and it was estimated that around 70–80% of the growth was accounted for urbanisation (Bairoch and Goertz 1986). While the majority of these studies deal with developing countries, there is less research concentrating on developed countries, like Japan. Hossain (2012) studied the Japanese carbon emission and urbanisation nexus. However, the study seems insufficient in terms of the inadequately specified model without quadratic GDP term and improper selection of estimation method from unit root test. It is evident that there are insufficient number of studies that explore how CO_2 emission is affected by GDP, energy consumption, trade and urbanisation in a developed country. Against this backdrop, this research aims at analysing how these factors affect the volume of CO_2 emission in Japan.

2 Model and Estimation Method

Theoretically, EKC was first introduced for modelling pollution and emission by Grossman and Krueger (1991). They argued that EKC is an inverted U-shaped or bell-shaped curve due to scale, structural, and technological effects. In the development stage, the economic growth of a country is high, and demand for natural resources rises, resulting in environmental degradation, termed as scale effect. The structure effect indicates the transition stage when the economic structure changes from the developing to developed state. After stepping into the developed stage, the economy becomes technologically sound and emits less CO_2. In addition, some scientists argue that the income elasticity of demand for environmental quality is possibly the reason for inverted U-shaped EKC (Beckerman 1992; Carson et al. 1997; McConnell 1997; Stern et al. 1996). Since environmental quality is a normal good, though some academics prefer to categorise it as a luxury good, the demand for environmental quality may increase with the level of income (Bruneau and Echevarria 2009; Martini and Tiezzi 2014; Pearce and Palmer 2005).

Since the theoretical model above suggests a bell-shaped or inverted 'U' shaped EKC, the quadratic term of income should be included in the empirical model. In the functional form, EKC can be modelled as follows:

$$E_t = f\left(Y_t, Y_t^2, \mathbf{X}_t\right) \tag{1}$$

Here, E_t, Y_t denote the emission of pollutants and per capita GDP in year t, respectively, and $\mathbf{X}_t$ be the vector of other factors that can influence emission. The equation above expresses the relationship between GDP and the environmental load. "Inverted U-shaped" relation suggests that the intensity of environmental pollution can be reduced when a country's income exceeds a turning point; it may grow in underdeveloped countries (Grossman and Krueger 1995). Hence, the literature on EKC assumes that GDP per capita can be positively associated with environmental load (e.g., CO_2), while its quadratic term can be negatively associated, which indicates the validity of EKC.

Following the basic idea about EKC, the influence of other factors has widely been examined with the framework. Among them, energy-electricity consumption is a typical example for those that can affect CO_2 emission, and its influence has been controlled in the literature of EKC as previously described (e.g., Al-mulali, Solarin, and Ozturk 2016; Ozturk and Acaravci 2013; Saboori and Sulaiman 2013b; Shahbaz et al. 2013).

The effect of urbanisation on CO_2 emissions has also been examined. The relationship between the two, however, is not yet conclusive and well understood (Martínez-Zarzoso and Maruotti 2011), while some country-specific studies have revealed a positive relation (e.g., Ozatac, Gokmenoglu, and Taspinar (2017); Pata (2018a, 2018b) in Turkey, Ali, Bakhsh, and Yasin (2019) in Pakistan, Ouyang and Lin (2017) in China). Hossain (2012) examined the relationship in Japan only to find no significant effect of urbanisation. Yet, it requires investigation to find the effect, since it did not consider the quadratic effect of GDP. Without the quadratic term as used, the model cannot control the non-linear effect of per capita GDP on CO_2 emissions, which potentially leads to biased estimation.

Table 1: Summary statistics.

	Obs.	Mean	Std.Dev.	Min.	Max	Unit
CO_2	51	923,348.7	298,802.4	232,781.2	1,266,010	Kilo ton
GDP	51	3632.03	1650.78	796.21	5848.02	Billion USD
ELE	51	5467.65	2436.98	1110.26	8710.03	kWh
POP	51	116.56	11.21	92.50	128.07	Million
UP OP	51	89.89	15.24	58.53	116.30	Million
X	51	317.81	252.22	18.60	806.11	Billion USD
M	51	375.08	236.36	755.18	825.24	Billion USD

ELE, electricity consumption; X, M, export/import of goods and services; POP, UPOP, total/urban population. Constant 2010 US dollar values for GDP, X, M.

Besides, the relationship with international trade has been examined considering the CO_2 component in trade (e.g. Farhani and Ozturk 2015; Ozatac, Gokmenoglu, and Taspinar 2017; Shahbaz et al. 2013, 2014). Applying "trade openness" variable, which is the proportion of trade in GDP, the effect of trade intensity in economic growth on CO_2 emissions is frequently analysed in the EKC framework. In the context of Japan, it is negatively associated with CO_2 emissions (Hossain 2012).

Based on the literature and the objective of the research, this study summarises below the model (Eq. (2)) to examine the impact of factors on CO_2 emission in Japan:

$$\ln CO_2PC_t = \alpha_0 + \alpha_1 \ln YPC_t + \alpha_2 \ln YPC_t^2 + \alpha_3 \ln ELEPC_t + \alpha_4 \ln UR_t + \alpha_5 \ln TO_t + \epsilon_t \qquad (2)$$

$\ln CO_2PC_t$ and $\ln YPC_t$ be the log of per capita CO_2 emissions (kt) and the log of GDP (constant 2010 USD) at time t, respectively. The effect of electricity use is controlled as represented by $ELEPC_t$, which denotes electricity consumption (kWh) per capita. UR_t denotes urbanisation factor, the ratio of urban population against the total. The effect of trade openness is also controlled with TO_t, which is the trade value (sum of export and import) divided by GDP: $TO_t = (X_t + M_t)/Y_t$. All data were extracted from the World Development Indicators (World Bank 2019) and transformed to logarithmic terms in the estimation. Due to data availability and stability of the estimation, the period examined is 1960–2010. Summary statistics are shown in Table 1. Figure 1 shows the trend of individual components considerd in the research.

Since time series data may contain unit roots, which may make the analysis spurious, the augmented Dickey-Fuller (ADF) test (Dickey and Fuller 1979) for unit root has been implemented. Additionally, Zivot-Andrews (Z-A) unit root test (Zivot and Andrews 2002), robust to endogenous structural break in time series, has also been carried out considering its existence in the data.

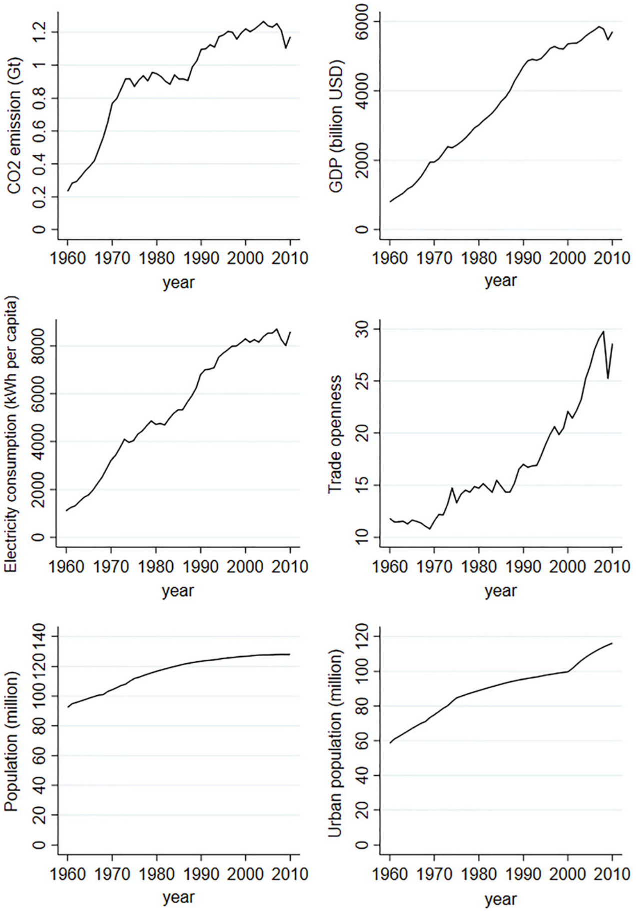

Figure 1: Shift of the covariates during the study period 1960–2010.

Considering the country-specific small sample size ($N = 51$) annual data of Japan as shown in Table 1, and mixed integration property (i.e. containing both $I(0)$ and $I(1)$ (Narayan and Smyth 2005)) as described later, this study applies autoregressive distributed lag (ARDL) approach (Pesaran, Shin, and Smith 2001) for the estimation of EKC relationship. Also, cointegration in the model is examined through the bounds testing approach. The error correction model (ECM) is applied to retain the robust estimation in the long-run relationship while correcting the short-term effect, and to examine the short-run relationship itself. This short-term model is described as follows:

$$\Delta\ln CO_2PC_t = \beta_0 + \Delta\beta_1 \ln CO_2PC_{t-1}\Delta\beta_2 \ln YPC_{t-1} + \Delta\beta_3 \ln (YPC)^2_{t-1} + \Delta\beta_4 \ln ELEPC_{t-1} + \Delta\beta_5 \ln UR_{t-1} + \Delta\beta_6 \ln TO_{t-1} + ECT_{t-1} + \epsilon_t \tag{3}$$

The short-term (difference term) shock is corrected with a one-year lagged error correction term (ECT), which also proxies the speed of adjustment in the long-term. The lag structure of the unit root test, ARDL bounds test and estimation are based on Bayesian criterion (BIC).

3 Empirical Results and Discussions

3.1 Unit Root Tests

Table 2 shows the result of the augmented ADF unit root test. The optimal lag structure of each variable is selected by BIC. While only urban population share and trade openness may not be stationary at level without trend, the ADF test considering trend indicates that all the variables other than CO$_2$ per capita have unit root at levels. At the first difference, all variables other than urban population share are stationary, suggesting that their integration properties are $I(0)$.

The result of Z-A test with endogenous structural break is presented in Table 3. Contrary to the result of ADF, all variables other than urban population share are stationary at $I(1)$. In contrast, urban population share does not have unit root, i.e. $I(0)$, with the intercept break. This suggests that the integration property for variables in the model is mixed with both $I(0)$ and $I(1)$.

Table 2: Unit root test: augmented Dickey-Fuller test.

	ADF: not trended		ADF: trended	
	$Z(t)$	**Lags**	**$Z(t)$**	**Lags**
$\ln CO_2PC_t$	−5.925***	0	−3.326*	0
$\ln YPC_t$	−6.980***	0	−2.226	0
$\ln (YPC_t)^2$	−6.371***	0	−1.797	0
$\ln ELEPC_t$	−7.116***	0	−2.657	0
$\ln UR_t$	−0.224	1	−2.854	1
$\ln TO_t$	0.435	0	−2.728	0
$\Delta\ln CO_2PC_t$	−4.790***	0	−5.457***	0
$\Delta\ln YPC_t$	−3.924***	0	−5.307***	0
$\Delta\ln (YPC_t)^2$	−3.952***	0	−5.411***	0
$\Delta\ln ELEPC_t$	−3.776***	0	−5.069***	0
$\Delta\ln UR_t$	2.159	1	−2.093	1
$\Delta\ln TO_t$	7.950***	0	−8.055***	0

The lags in the test are selected by BIC ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$.

Table 3: Unit root test: Zivot and Andrews with structural break.

	Break: intercept			**Break: trend**		
	min.t	**Lags**	**Break**	**min.t**	**Lags**	**Break**
$\ln CO_2PC_t$	−3.748	0	1968	−4.714	0	1970
$\ln YPC_t$	−2.667	0	1997	−3.060	0	1990
$\ln(YPCt)^2$	−2.384	0	1997	−2.952	0	1990
$\ln ELEPC_t$	−2.779	0	2001	−3.658	0	1969
$\ln UR_t$	−7.572***	1	2001	−3.542	1	1997
$\ln TO_t$	−3.714	0	2002	−4.006	0	1992
$\Delta\ln CO_2PC_t$	−7.510***	0	1971	−6.301***	0	1979
$\Delta\ln YPC_t$	−6.858***	0	1970	−5.833***	0	1975
$\Delta\ln(YPC_t)^2$	−6.600***	0	1970	−5.760***	0	1975
$\Delta\ln ELEPC_t$	−6.874***	0	1974	−5.775***	0	1981
$\Delta\ln UR_t$	−5.919***	1	2001	−3.374	1	1985
$\Delta\ln TO_t$	−8.294***	0	1970	−8.705***	0	1972

The lags in the test are selected by BIC ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$.

Table 4: ARDL bounds test for cointegration.

ARDL (1, 2, 3, 4, 3, 0)		**$F = 3.896$**	
$k = 5$		**$I(0)$**	**$I(1)$**
Critical values	1%	3.41	4.68
	5%	2.62	3.79
	10%	2.26	3.35
Diagnostics tests		**χ^2**	**p-Value**
ARCH-LM		0.003	0.956
B-G		1.939	0.164
RESET		3.03	0.048

Lag order is selected by BIC., ARCH-LM, Lagrange multiplier (LM) test for autoregressive conditional heteroscedastic effect; B-G, Breusch-Godfrey LM test for autocorrelation; RESET, Ramsey RESET test for model specification.

3.2 ARDL Bounds Testing for Cointegration

Table 4 presents the results of the ARDL bounds test and diagnostics tests. F-statistics in bounds test is larger than 5% critical value, showing that the null hypothesis of no level relationship is rejected at the significance level.

Table 5: Estimates of the long-run relationships.

ARDL-ECM(1, 2, 3, 4, 3, 0)			
Dep. var = $1nCO_2PC_t$	**Coef.**		***t***
Long-run relationships			
$lnYPC_t$	18.840***		3.29
$ln(YPC_t)^2$	−0.932***		−3.52
$lnELEPC_t$	0.628		1.63
$lnUR_t$	−1.672**		−2.10
$lnTO_t$	0.558*		1.89
Obs.		47	
$Adj.R^2$		0.839	
Durbin-Watson stat.		2.304	

***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$.

This indicates that there is a cointegration relationship between variables at least at 5% significance level.

Diagnostics tests show that the model is not significantly affected by heteroscedastic effect and autocorrelation, and the specification is valid at 1% level of significance (Table 5).

3.3 Stability Test

Cumulative sum (CUSUM) and its squared term (CUSUMSQ) have been tested to examine the stability of ARDL-ECM estimates (Figure 2). The result suggests that both CUSUM and CUSUMSQ values are within the 5% limit in the study period.

3.4 ARDL Estimates on the EKC Relationships

3.4.1 Long-Run Relationships

The result of the long-run relationship is also shown in Table 5. GDP per capita shows a significant and positive effect, while its squared term seems to negatively affect CO_2 emissions per capita. This result aligns with the EKC literature, suggesting an inverted-U relationship between economic growth and carbon emissions.

The urban population ratio shows its negative relation to carbon emissions in the long run. The variable may have had a negative impact if those from other

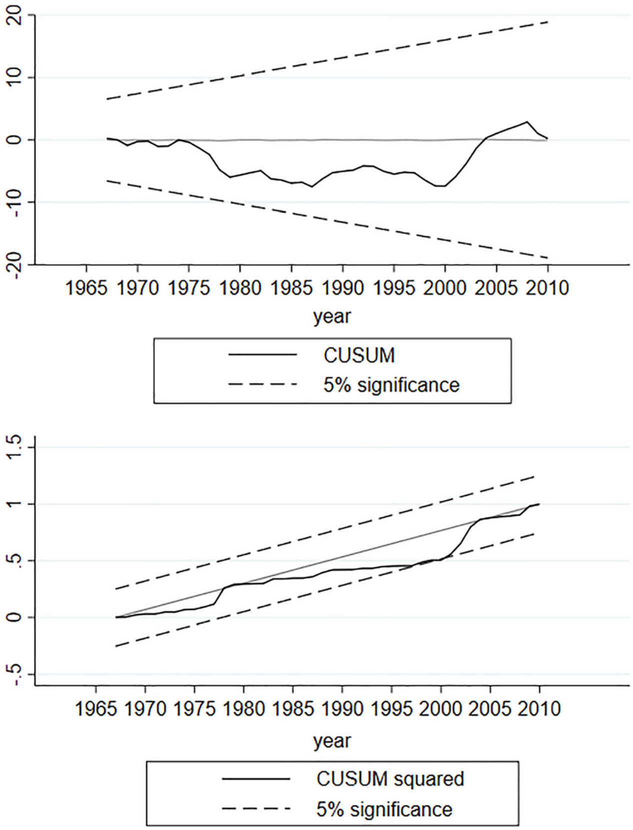

Figure 2: CUSUM and CUSUMSQ plot.

factors (e.g. GDP, electricity etc.) had been controlled. Trade openness has only a weakly positive impact on domestic carbon emissions. Electricity consumption per capita shows no significant result.

3.4.2 Short-Run Relationships

Table 6 shows the result of the short-run relationship. The significance of lagged ECT indicates that the speed of adjustment variable is effective on the estimation. Combined with the result of the bounds test, this result supplements the robustness in the long-run relationship of cointegration.

With a one-year lag, differences of GDP per capita show a positive and significant relation to CO_2 emissions per capita, while its squared term shows a

Table 6: Estimates of the short-run relationships.

ARDL-ECM(1, 2, 3, 4, 3, 0)		
Dep. var = 1nCO_2PCt	**Coef.**	***t***
Short-run relationships		
ΔlnYPC$_t$	−3.720	−1.18
ΔlnYPC$_t$-1	8.038**	2.26
Δln(YPC$_t^2$)	0.177	1.13
Δln(YP$_t$-1)^2	−0.400**	−2.27
Δln(YP$_t$-2)^2	−0.008	−0.72
ΔlnELEPC$_t$	0.427**	2.07
ΔlnELEP$_t$-1	0.528***	3.61
ΔlnELEP$_t$-2	0.129	0.82
ΔlnELEP$_t$-3	0.383***	3.08
ΔlnUR$_t$	1.069	0.74
ΔlnUR$_t$-1	0.442	0.21
ΔlnUR$_t$-2	1.736	0.95
ECT$_t$-1	−0.440***	−3.22
Cons.	43.833***	−3.49

The lags in the test are selected by BIC ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$.

negative effect. Electricity consumption per capita also shows a significant and positive effect on carbon emissions with the difference in t, $t-1$, $t-3$. Short-run effect of electricity consumption is suggested to have positively linked to carbon emissions, while no significant relationship in the long-run has detected. Contrary to the result on the long-run relationship, urbanisation in differenced terms are not significant.

According to the empirical model or Eq. (2), the estimated coefficient of per capita GDP greater than zero and the estimated coefficient of the squared term of it less than zero confirm the inverted 'U' shaped EKC (see Shahbaz and Sinha 2019). The results provided in this paper (see Section 3.4.1) confirm that Japan initially had negative impacts on the environment but gradually contributed to environmental soundness, potentially confirming inverted U-shaped EKC. The findings of this study are in line with some previous studies, which also confirmed inverted U shaped EKC, for OECD countries (Galeotti et al. 2006), for France (Aug 2007; Iwata et al. 2010), for Turkey (Halicioglu 2009), for China (Jalil and Mahmud 2009; Pao and Tsai 2010), for India (Pao and Tsai 2010), as well as for Algeria, Egypt, Lebanon, Jordan and other MENA countries (Arouri et al. 2012).

However, previous studies in Japan provided mixed results. For instance, no evidence of EKC was found in various investigations (Cho et al., 2014; Lipford and Yandle, 2010; Hossain 2012). Contrary, Onafowora and Owoye (2014) and Yaguchi et al. (2007) found inverted U-shaped EKC for Japan. Japan is contributing more to environmental soundness, through their technological advancement. In addition, it might be the cause of higher income elasticity of demand for environmental quality. In a different context, urbanisation was found to affect CO_2 emission both positively and negatively (Chen, Jin, and Lu 2019). This research supports the finding of Li and Lin (2015) that has argued that urbanisation reduces the CO_2 emissions in high-income countries. However, in short-run no significant relation was found.

4 Conclusion

This study aimed at analysing the impacts of economy (i.e., GDP), energy consumption (electricity consumption), urbanisation (urban population against total population), and trade openness (sum of trade value divided by GDP) on the volume of CO_2 emission both in short and long terms in Japanese economy, using the data of 50 years from 1960 to 2010. The findings suggest that the inverted U-shaped relation between economic growth and emission in both durations follows the EKC theorem. However, in the long term, energy consumption per capita has no significant impact on emissions. This may be due to the unique population growth rate of Japan. From 1960 till 2010, the population in Japan increased at a moderate pace, and since 2011 it has started to decline. This may have caused no significant impact on emission. Besides, the effect of trade openness on emission was found slightly positive, which seems usual. Apparently, the country's trade volume does not directly affect the emission of CO_2. However, a higher level of economic activity and high emitting goods production process may result in higher emissions. Assuming Japan's high level of technological advancement, it seems rational that trade may have an insignificant impact.

In contrast, the ratio of the urban population shows a negative impact on carbon emission in the long run. In a rapidly changing society where international trade volumes are enhancing, energy consumption is high rocketing, and urbanisation is becoming a regular practice, research about climate change and global warming is exploring newer and newer fields to be investigated. Accordingly, further research may be conducted in other developed countries to compare and contrast how the factors affect their emission volume and the consequences.

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