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Modelling the globalization-CO₂ emissions nexus: Evidence from Quantile-on-Quantile Approach

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Abstract: Sustainable development policies for achieving net-zero emissions require understanding the factors that influence CO₂ emissions. Capitalizing on the limitations of the existing literature, this study applies the Quantile-on-Quantile (QQ) approach to investigate economic globalization's impact on CO₂ emissions in Australia for 1970-2018. The results from the QQ revealed a positive feedback linkage between globalization and CO₂ emissions at all quantiles. The results further indicated that while there is a positive feedback linkage between economic growth and CO₂ emissions at most quantiles, a positive feedback interconnection exists between CO₂ pollution and coal consumption at all quantiles. As a robustness check, we employed the quantile regression (QR) test, and the results from QR are consistent with the findings from QQ. The consistency of the results suggests that these study findings are reliable and suitable for informing policies that seek to address CO₂ emissions in Australia. The policy implications for Australia are discussed.

Keywords: Australia; Globalization; CO₂ emissions; Quantile-on-Quantile approach

JEL Classification: C14; C22; F64; Q56

1. Introduction

Undoubtedly, economic development in advanced economies improves living standards and comes with environmental costs (Acheampong, 2019; Shahbaz, Shahzad, Ahmad, & Alam, 2016). Most developed economies recognize the dangers associated with economic growth and have implemented several environmentally sustainable strategies to mitigate the adverse effects of economic growth and development on the environment (Adebayo et al., 2021; Alola et al., 2019). Such interventions have achieved promising outcomes, but not at the pace at which global environmental concerns are increasing. The twenty-first century has been dubbed the “*jet age*,” in which the whole world has been reduced to a tiny village due to technological advancements. The advantages of this transition from localized individualized states to an internationally integrated society are numerous (Sarkodie et al., 2020). Thus, the integration of distant economies through capital flows, trade, foreign direct investment, and technological opportunities contribute significantly to economic growth and development (Shahbaz, Shahzad, Mahalik, & Hammoudeh, 2017).

While economic globalization promotes economic development, it also impacts the environment (Hipolito Leal & Cardoso Marques, 2019; Rahman, 2020; Shahbaz, Shahzad, Mahalik, et al., 2017). Theoretically, the impact of globalization on CO₂ emissions is priori uncertain. Thus, there is a conflicting theoretical debate on economic globalisation-CO₂ emissions relationships. For instance, the proponents of the pollution-haven hypothesis opine that developing countries have been the host of environmental polluting industries from the developed economies due to the stringent environmental regulatory policies in advanced economies. The strict environmental regulatory policies in the advanced economies impose a high cost on degrading environmental industries. To remain competitive, these environmental degrading industries relocate to developing countries with weak environmental regulatory policies (Wheeler, 2001). Contrarily, the proponents of the pollution-halo hypothesis argue that globalization reduces CO₂ emissions as it ensures the transfer and spread of environmentally efficient technologies, knowledge, and standard environmental management practices in the host countries (Acheampong, Samuel Adams, & Boateng, 2019; Doytch & Uctum, 2016; Pao & Tsai, 2011). Similarly, Krugman, Obstfeld, and Melitz (2017) argue that globalization can retard CO₂ emissions as it could simulate countries to change the mix of their production and consumption as they become wealthier. With the conflicting theoretical debates, the empirical findings remain inconsistent and inconclusive. For instance, some of the studies have reported

a positive effect of globalization on CO₂ emissions (Abdouli, Kamoun, & Hamdi, 2018; Meng et al., 2018; Shahbaz, Nasir, and Roubaud, 2018), while others have reported a negative effect of globalization on CO₂ emissions (Liu, Hao, and Gao, 2017; Lv & Xu, 2018; Shujah Ur et al., 2019). The last group of empirical studies have also reported a neutral effect of globalization on CO₂ emissions (Dogan & Turkekul, 2016; Haseeb, Xia, Danish, Baloch, & Abbas, 2018; Xu et al., 2018).

While recent studies have attempted to probe the environmental impact of globalization on globalization on CO₂ emissions, You and Lv (2018) argue that the environmental effect of globalization requires further scrutiny due to the limitations of the existing studies. For instance, prior empirical studies have either used trade openness or foreign direct investment as a proxy for economic globalization to examine their respective effect on CO₂ emissions (Acheampong, 2018; Acheampong et al., 2019; Ning & Wang, 2018; Sarkodie & Strezov, 2019; Shahbaz, Nasreen, Ahmed, & Hammoudeh, 2017). However, neither trade openness nor foreign direct investment is an adequate measure of economic globalization since they fail to capture other economic globalization dimensions such as the spread of technology, capital controls, and knowledge beyond borders (Lv & Xu, 2018). It is argued that overlooking these dimensions of economic globalization can seriously underestimate economic globalization's effect on CO₂ emissions (Lv & Xu, 2018; You & Lv, 2018).

Also, the prior empirical studies on the relationship between globalization and CO₂ emissions are restricted to the traditional parametric econometric approaches (Shariff et al. 2020; Shahbaz et al. 2020; Adebayo and Kirikkaleli et al. 2021). However, parametric estimators are not robust to outliers and sometimes fail to account for slope heterogeneity (Dzator & Acheampong, 2020). Therefore, understating the effect of economic globalization on CO₂ emissions requires an advanced novel econometric approach robust to outliers and could account for slope heterogeneity. However, using a nonparametric econometric estimator such as the Quantile-on-Quantile (QQ) approach to examine the impact of economic globalization on CO₂ emissions remains rare in the literature. Therefore, this study seeks to fill these knowledge gaps by applying the QQ approach to investigate economic globalization's effect on CO₂ emissions in Australia for 1970-2018 while controlling economic growth and coal consumption.

Why Australia? Investigating the impact of globalization on CO₂ emissions while controlling for economic growth, coal consumption is crucial since Australia is a prosperous nation with

natural resources with an enormous territory area. For a century, open immigration policies are critical for sustainable growth and a liberalized economic and trade environment. Australia has gained in the last four decades due to the emergence of globalization due to reducing trade barriers, smooth flows of capital, technological diffusion, labour mobility, and better use of resources. This research focuses on Australia, which has unique features which make the nation particularly fascinating to study. Australia is ranked 15th position globally in terms of greenhouse gas (GHGs) pollution. Besides, Australia is the second biggest coal exporter and the world's leading liquefied natural gas exporter (LNG) (CarbonBrief, 2021). Despite the increased use of gas and renewables, mainly rooftop solar, the electricity system heavily depends on coal. It is also highly susceptible, including excessive temperatures, droughts, bushfire, and agriculture damage, to the effects of climate change. Australia is off-track to reducing emissions by 26-28% by 2030 compared to the 2005 pace. Also, Australia rendered its climate commitment to the Paris climate talks in August 2015 (CarbonBrief, 2021). By 2030, Australia pledged to reduce emissions by 26-28% relative to the 2005 level. Also, Australian energy consumption increased by 0.6% between 2018 and 2019 to achieve 6,196 petajoules. Figure 1 suggests that fossil fuels (oil, gas, and coal) contributed to 94% of the primary energy mix in Australia between 2018 and 2019 with oil (39%), coal (29%), natural gas (26%) and renewable energy (6%). Finally, Australia is firmly integrated with the rest of the world and pursuing some trade agreements, including the Comprehensive and Progressive Agreement for Trans-Pacific, Peru-Australia Free Trade Agreement, the Indonesia-Australia Comprehensive Economic Partnership and Hong Kong-Australia Free Trade Agreement. When these trade agreements are finalized, they will cover 88% of Australia's trade (Department of Foreign Affairs and Trade, 2019). For these reasons, focusing on Australia will contribute significantly to the literature and further inform policies for achieving the net-zero by 2050 in Australia.

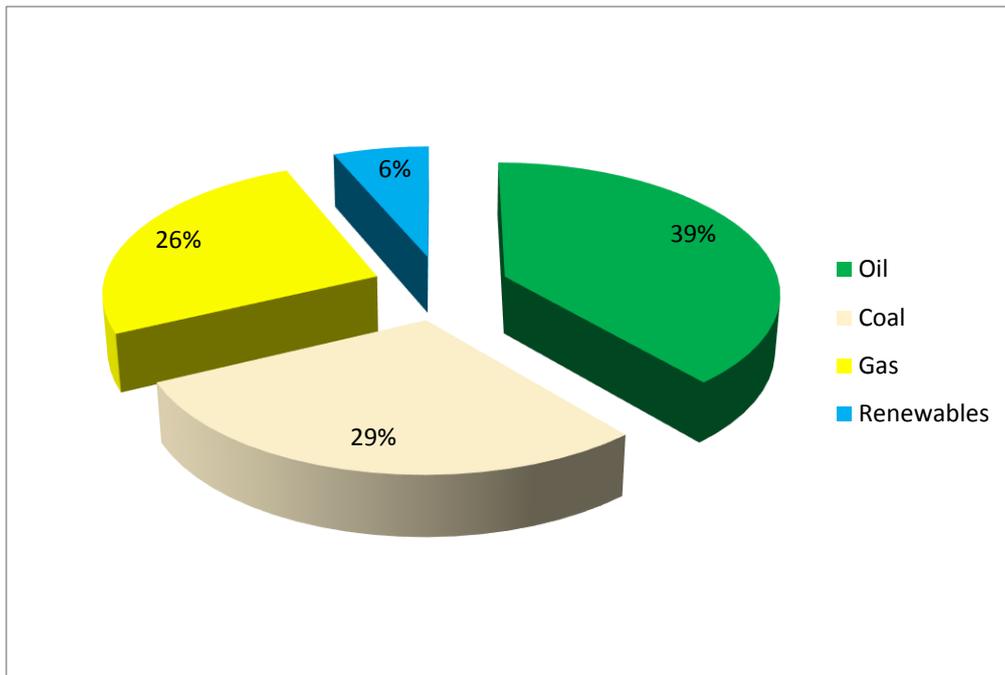


Fig 1. Distribution of Australia's energy consumption
Source: Department of Industry, Science, Energy and Resources (2020)

This study contributes to the literature in the following ways: To the authors' knowledge, this is the first empirical study to employ Sim and Zhou (2015) QQ technique to examine the impact of economic globalization on CO₂ emissions in Australia. Bekun et al. (2021) and Sharif et al. (2020) argue that econometric approaches are crucial in achieving unbiased research outcomes and recommend using effective advanced novel econometric methods. The QQ method is advantageous because it can combine the concepts of quantile regressions (QR) and nonparametric estimation analysis distinguishes it. The QQ approach is robust to outliers and could account for slope heterogeneity. Second, the literature review suggests that most empirical studies are based on panel data modelling techniques. Although estimates from panel data techniques are efficient, its conclusions and policy implications may not apply to individual countries due to countries heterogeneities (Acheampong 2018; Coggin 2019). With this argument, this study further adds to the body of knowledge by utilizing a time-series approach to analyze the effect of globalization on CO₂ emissions to provide policy guidelines to Australia. Finally, this study relies on the KOF economic globalization index to provide a broader perspective than the existing studies that either uses trade openness or foreign direct as a proxy for globalization. The KOF economic globalization index is multidimensional, capturing trade in goods and services, trade partner diversity, foreign direct investment,

portfolio investment, international debt, international reserves, and international income payments (Gygli et al., 2019).

The remaining section of this paper is outlined as follows: Literature review is presented in Section 2. Section 3 presents methodology and data, while Section 4 presents empirical findings and discussions. Conclusion and policy implications are presented in section 5.

2. Review of related literature

The pollution-haven and pollution-halo hypothesis are the main theoretical framework for studying the relationship between globalization and CO₂ emissions. The proponents of the pollution-haven hypothesis opine that developing countries have been the host of environmental polluting industries from the developed economies due to the stringent environmental regulatory policies in advanced economies. The strict environmental regulatory policies in the advanced economies impose a high cost on degrading environmental industries. To remain competitive, these environmental degrading industries relocate to developing countries with weak environmental regulatory policies (Wheeler, 2001). The pollution-haven hypothesis implies that globalization reduces environmental pollution, such as mitigating CO₂ emissions in developed economies while it increases CO₂ emissions in developing countries. Some of the existing empirical results have collaborated with the pollution-haven hypothesis using either a time series or panel data approach. For instance, S. S. Akadiri, Lasisi, Uzuner, and Akadiri (2019) revealed that globalization worsens CO₂ emissions. The study of Shahbaz, Shahzad, and Mahalik (2017) also found that globalization induces higher CO₂ emissions in Japan.

For BRICTS countries, Abdouli et al. (2018) found that globalization proxied by FDI increases CO₂ emissions. Further, in Pakistan, Khan and Ullah (2019) found that economic, political, and social globalization contributes to higher CO₂ emissions. For the case of 25 developed countries, Shahbaz, Shahzad, Mahalik, et al. (2017) indicated that globalization contributes to CO₂ emissions. For 83 countries, You and Lv (2018) showed that economic globalization contributes to CO₂ emissions. Using panel data for 101 countries, Meng et al. (2018) also revealed that globalization measured by trade openness worsens CO₂ emissions. Seyi Saint Akadiri, Alkawfi, Uğural, and Akadiri (2019) also showed that globalization worsens CO₂ emissions in Italy. For South Africa, Kohler (2013) also found that trade openness worsens CO₂ emissions. Further, the study of Acheampong, S. Adams, and E. Boateng (2019) found that while FDI reduces CO₂ emissions, trade openness increases CO₂ emissions in 46 sub-

Saharan African countries. Also, Shahbaz et al. (2018) found that FDI contributes to CO₂ emissions in France. Shahbaz, Mallick, Mahalik, and Loganathan (2015) further observed that globalization increases CO₂ emissions in India.

Contrarily, the proponents of the pollution-halo hypothesis argue that globalization reduces CO₂ emissions as it ensures the transfer and spread of environmentally efficient technologies, knowledge, and standard environmental management practices in the host countries (Acheampong et al., 2019; Doytch & Uctum, 2016; Pao & Tsai, 2011). Similarly, Krugman et al. (2017) argue that globalization can retard CO₂ emissions as it could simulate countries to change the mix of their production and consumption as they become wealthier. Some of the existing empirical findings have confirmed the pollution-halo hypothesis using time series or panel data approaches. For instance, Lee and Min (2014) found that globalization curbs CO₂ emissions in a panel of 225 countries. For 112 Chinese cities, Liu et al. (2017) found that globalization measured by FDI reduces CO₂ emissions. Also, for 15 emerging economies Lv and Xu (2018) found that globalization measured by FDI mitigates CO₂ emissions. Rahman (2020) also observed that globalization reduces CO₂ emissions. Also, Shahbaz, Solarin, and Ozturk (2016) indicated that globalization improves CO₂ emissions in a panel of 19 Africa countries.

Similarly, Shujah Ur et al. (2019) revealed that globalization reduces carbon emissions in 16 Central and Eastern Africa countries. Focusing on the Asia Pacific Economic Cooperation countries, Zaidi, Zafar, Shahbaz, and Hou (2019) indicated that globalization reduces carbon emissions. For the case of 5 South-East Asian countries, Zhu, Duan, Guo, and Yu (2016) suggested that FDI lowers carbon emissions. Similarly, Acheampong (2018), using the system GMM-PVAR approach, found that trade openness reduces carbon emissions in Asia-Pacific, MENA, sub-Saharan Africa, and globally. In another study, Shahbaz, Kumar Tiwari, and Nasir (2013) found that globalization measured by trade openness improves CO₂ emissions in South Africa. Similarly, Zhang and Zhou (2016) found that FDI lowers carbon emissions from western, eastern, and central regions in China.

Inconsistent with both the pollution-haven and pollution-halo hypothesis, another empirical study revealed that globalization has a neutral effect on CO₂ emissions. For instance, Haseeb et al. (2018) utilized the dynamic seemingly unrelated regression and Dumitrescu-Hurlin Causality approach and found that globalization does not affect carbon emissions in BRICS countries. Also, Boutabba (2014) revealed that trade openness exerts no effect on carbon

emissions in India. Dogan and Turkekul (2016), using ARDL, also found that trade has no significant relationship with carbon emissions in the USA. Xu et al. (2018) found that globalization has an insignificant effect on carbon emissions in Saudi Arabia. Given these conflicting theoretical and empirical findings, further studies are needed to reconcile the inconsistency in the literature. Existing studies have employed different econometric approaches and different globalization measures to examine the effect of globalization on CO₂ emissions. The survey of the empirical literature reveals that the results of the existing studies are conflicting and still inconclusive as some studies report either globalization increase, reduce or have a negligible effect on CO₂ emissions. Therefore, this study contributes to the literature by applying the QQ approach to investigate economic globalization's impact on CO₂ emissions in Australia for 1970-2018 while controlling economic growth and coal consumption.

3. Methodology and Data

3.1. Quantile-on-quantile regression approach

This study utilized the Sim and Zhou (2015) QQ to examines the linkage between CO₂ emissions and coal consumption, economic growth, and globalization are briefly described in this section. The QQ approach is an improvement of the traditional quantile regression (QR) model that allows researchers to investigate how an indicator's (variable) quantiles influence the quantiles of another indicator. The QQ method employs a hybrid of nonparametric estimation and QR. The influence of independent variables on the different quantiles of the dependent variable is first estimated using conventional QR. The QR, which Koenker and Bassett (1978) developed, is an improvement of the traditional linear regression (LR) model.

In contrast to the OLS estimator, the QR assesses the influence of the independent variable at both tail and center of the dependent variable's distribution, enabling a more thorough examination of the relationship between variables. Secondly, the spatial influence of a single quantile of the independent indicator on the dependent indicator is estimated using local linear regression (LR). The "curse of dimensionality" issue linked with strictly nonparametric models is avoided with the local LR proposed by Cleveland (1979) and Stone (1977). The underlying principle behind this reduction dimension strategy is to construct an LR locally around each point of the data in the dataset, offering closer neighbors more weight. As a result of integrating these two methods, it is feasible to model the association between quantiles of dependent and independent variables, yielding more detail than other measurement approaches, including QR

and OLS. For instance, the QQ approach is suggested to assess the influence of the quantiles of X on Y quantiles of a nation. This method has its preliminary point in the QR model below:

$$Y_t = \beta^\theta(X_t) + \mu_t^\theta \quad (1)$$

where Y_t and X_t portray the dependent variable in period t and the independent parameter in period t. θ stands for θ th quantile of Y conditional distribution and is an error term of the quantile whose θ th conditional quantile is 0. The unknown function is illustrated by $\beta^\theta(.)$ because previous information connection X and Y is unknown. The effect of X on the distribution of Y is measured using this QR model, which permits the influence of X to vary across various Y quantiles. Since there is no established hypothesis about the functional form of the linkage between X and Y, the primary benefit of this specification is its stability. One limitation of the QR method is its inability to capture complete dependency. In this respect, the QR model ignores the probability that the existence of X shocks influences the association between Y and X. The results of big positive X shocks, for instance, can vary from those of small positive X shocks. Furthermore, negative and positive X shocks will cause Y to respond asymmetrically.

Thus, to investigate the linkage between θ th quantile of Y and τ th of X, represented by X^τ , is investigated in X^τ neighborhood utilizing local linear regression. The unknown function which is depicted by $\beta^\theta(.)$ can be estimated as a first-order Taylor expansion centered on X^τ quantile as follows;

$$\beta^\theta(X_t) \approx \beta^\theta(X^\tau) + \beta^{\theta\iota}(X^\tau)(X_t - X^\tau) \quad (2)$$

Where $\beta^{\theta\iota}(X_t)$ partial derivative with regard to X is illustrated by $\beta^{\theta\iota}$ which is also recognized as response and is comparable to the coefficient slope in an LR framework in terms of meaning. The notable feature of Equation 2 is that $\beta^\theta(X^\tau)$ and $\beta^{\theta\iota}(X^\tau)$ parameters are twice indexed in τ and θ . Given that $\beta^\theta(X^\tau)$ and $\beta^{\theta\iota}(X^\tau)$ are functions of θ and X^τ and X^τ is a function of τ . It is glaring that $\beta^{\theta\iota}(X^\tau)$ and $\beta^\theta(X^\tau)$ are both function of τ and θ respectively. Besides, $\beta^\theta(X^\tau)$ and $\beta^{\theta\iota}(X^\tau)$ can also be represented as $\beta_0(\theta, \tau)$ and $\beta_1(\theta, \tau)$. Therefore, Equation 2 can be transformed as follows:

$$\beta^\theta(X_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(X_t - X^\tau) \quad (3)$$

When equation 3 is substituted into Equation 1 to obtained Equation 4 as follows:

$$Y_t = \underbrace{\beta_0(\theta, \tau) + \beta_1(\theta, \tau)(X_t - X^\tau)}_{(*)} + \mu_t^\theta \quad (4)$$

In Equation 4, θ th conditional quantile Y is depicted by (*). Nevertheless, contrary to standard conditional quantile function, this illustration discloses the interconnection between θ th of Y and τ th quantile of X because β_0 and β_1 parameters twice index in θ and τ . These parameters may differ throughout various distinct θ th quantiles of Y and τ th quantiles of X. Furthermore, no linear association between the variables quantiles under analysis is presumed at any point. As a result, Equation 4 calculates the overall dependency structure between Y and X based on the correlation between their separate distributions.

Also, X_t and X^τ is replaced by \widehat{X}_t and \widehat{X}^τ when estimating Equation 4. The parameters b_0 and b_1 , which are β_0 and β_1 estimates are gathered by fixing the following issue of minimization:

$$\min_{b_0, b_1} \sum_{i=1}^n \rho_\theta [Y_t - b_0 - b_1(\widehat{X}_t - \widehat{X}^\tau)] K \left(\frac{F_n(\widehat{X}_t) \square - \tau}{h} \right) \quad (5)$$

Where quantile loss function is illustrated by $\rho_\theta(u)$, and $\rho_\theta(u) = u(\theta - I(u < 0))$, I which is the usual function of the indicator. The function of kernel and h , which is the parameter kernel bandwidth, is depicted by $K(\cdot)$. The Gaussian kernel is utilized in this analysis to weigh the observations in the X^τ neighborhood, which is one of the most common functions of the application kernel in finance and economics due to its simplicity, computation, and reliability.

Around Zero, the kernel of Gaussian is symmetric, and it gives lower observations of weights that are further out. These weights are inversely proportional to the distance between the analytical distribution function of \widehat{X}_t , indicated by $F_n(\widehat{X}_t) = \frac{1}{n} \sum_{k=1}^n I(\widehat{X}_k > \widehat{X}_t)$, and function of distribution value that aligns with the X^τ illustrated by τ . When utilizing a nonparametric approach, bandwidth selection is crucial. The bandwidth governs the smoothness of the corresponding approximation since it specifies the scale of the neighborhood surrounding the target point. A wider bandwidth suggests a higher risk of estimation distortion, while a smaller bandwidth illustrates a higher risk of prediction uncertainty. As a result, a bandwidth must be chosen that provides equilibrium between variances. A bandwidth $h=0.05$ parameter was used in this analysis, as recommended by Sim and Zhou (2015).

3.2. Data

This study examines the interconnection between CO₂ and globalization, GDP, and coal consumption. The dataset for this empirical analysis covers between 1970 and 2018 (49 observations). The description, source, and measurement of the dataset are depicted in Table 1. Furthermore, a summary of the variables utilized in this empirical analysis is presented in Table 2. The outcomes from Table 2 disclosed that economic growth scores better on average due to its higher mean. The standard deviation is a gauge of the amount of variation or dispersion of a set of values. Thus, the standard deviation is utilized to check the variable which had more consistent scores. CO₂ has the lowest standard deviation, which indicates that the scores are less spread out from the mean. Thus, CO₂ has a more consistent score. Skewness results reveal that CO₂ emissions and GDP are positively skewed while coal use and globalization are negatively skewed. The value of the Kurtosis disclosed that all the variables are platykurtic. The Jaque-Bera statistics unveil that the series are normally distributed. The correlation between the indicators is depicted in Figure 2 (correlation box), which ranges from blue (positive correlation) to red (negative correlation). The outcomes of the correlation box disclosed that GDP, globalization, and coal consumption positively correlates with CO₂ emissions, which infers that an increase in coal consumption, globalization, and GDP is associated with an increase in CO₂ emissions.

Symbol	Variables	Unit	Source
CO ₂	Environmental degradation	Per Capita Emissions	BP
GDP	Economic Growth	GDP per capita	WDI
COAL	Coal Consumption	Exajoule	BP
GLO	Globalization	Index based on FDI, trade, and portfolio investment	Gygli et al. (2019): revised KOF globalization index

Table 2: Descriptive Statistics				
	CO ₂	COAL	GDP	GLO
Mean	7.871503	459.7481	39791.02	70.95093
Median	7.687916	468.2643	37133.04	72.21075
Maximum	9.594431	677.2213	56832.05	81.64704
Minimum	6.736522	231.6946	26120.62	56.84417
Std. Dev.	0.745371	135.3737	10208.50	8.387600
Skewness	0.564470	-0.158214	0.259098	-0.112517
Kurtosis	2.649423	1.752200	1.595745	1.428413
Jarque-Bera	2.853049	3.383311	4.574272	5.146074
Probability	0.240142	0.184214	0.101557	0.076303
Observations	49	49	49	49

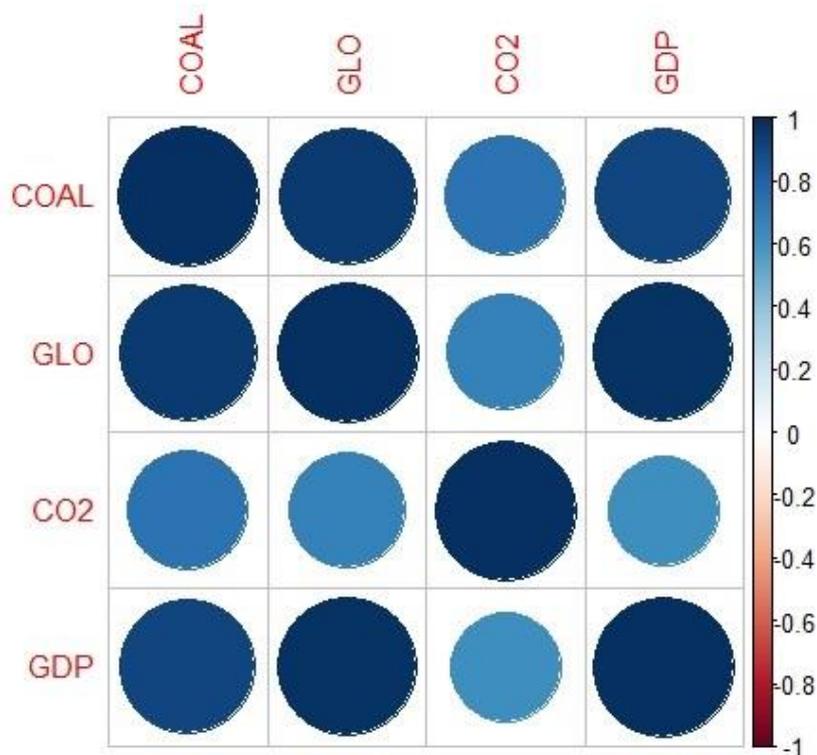


Figure 2: Correlation Box

4. Empirical results

4.1. Pre-estimation tests

It is essential to conduct a linearity test to ascertain the variables' linearity feature. Centered on this, this study utilized the BDS test to examine the nonlinearity of the variables. The outcomes of the BDS test are illustrated in Table 3. Centered on these outcomes, utilizing the normal linear techniques will produce disingenuous outcomes. Thus, we employed a non-linear method to assess the influence of GDP, GLO and COAL on CO₂ emissions in Australia. Moreover, we verify the stationarity characteristics of the variables by employing the traditional ADF and PP unit root tests. The outcomes of the ADF ad PP unit root tests are presented in Table 4, and the results disclosed that all the series are non-stationary at level. Nevertheless, all the variables are found to be stationary at first difference.

	M=2	M=3	M=4	M=5	M=6
CO ₂	13.063*	13.751*	13.807*	13.519*	13.349*
GDP	30.367*	31.335*	33.245*	36.306*	40.634*
COAL	32.413*	34.234*	36.255*	39.208*	43.220*
GLO	31.148*	32.649*	34.768*	38.262*	42.963*

Note * signifies 0.01 level of significance

Variables	ADF		PP	
	At Level	First Difference	At Level	First Difference
CO ₂	-2.1891	-8.2146*	-2.1384	-8.3632*
GDP	-2.1840	-5.5587*	-2.1840	-5.5170*
COAL	-0.1498	-4.2946*	0.2973	-4.2679*
GLO	-0.3155	-5.4783*	-0.6732	-5.4837*

Note: *, ** and *** illustrates 0.01, 0.05 and 0.10 level of significance correspondingly.

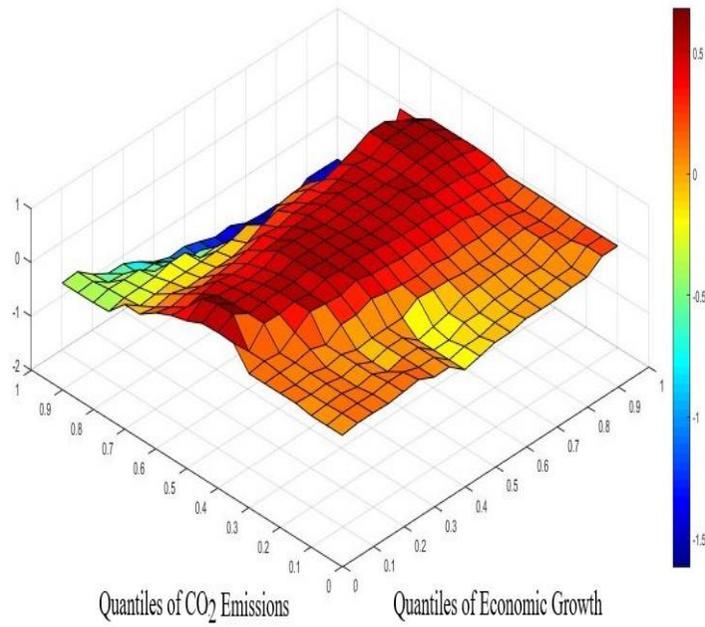
4.2. QQ approach results

This part of the research reveals the main empirical outcomes of the QQ analysis of the impact of trade openness, GDP, and renewable energy consumption on CO₂ emissions in Australia. Fig. 2(a–f) reveals the slope coefficient estimates, $\beta_1(\theta, \tau)$, which catches the influence of the τ th quantile of X on the θ th quantile of Y, at various values of θ and τ for Australia. The QQ outcomes are illustrated in Figure 3(a–f). Figure 3a discloses the effect of GDP on CO₂ emissions in Australia. The slope coefficient ranges from -1.5 to 0.5. The impact of GDP on CO₂ is negative at lower quantiles of GDP (0.1–0.3) and higher quantiles of CO₂ emissions (0.7–0.95). Furthermore, the value of slope coefficient is positive and weak in middle and higher (0.35–0.95) quantiles of GDP and lower and middle (0.1–0.75) quantiles of CO₂ emissions. These outcomes indicate that both negative and positive effects exist between CO₂ emissions and GDP in Australia; nevertheless, there is evidence of weak effects. The influence of CO₂ on GDP in Australia is depicted in Figure 3b. The scale of the slope coefficient ranges from 0 to 10. The influence of CO₂ on GDP is positive at most combinations of quantiles of GDP and CO₂ emissions; however, the effect of CO₂ on GDP is positive and strong in the higher quantiles (0.80–0.95) quantiles of CO₂ and lower quantiles of GDP (0.1–0.35) as revealed by the scale of the slope coefficient. This demonstrates that an upsurge in GDP is attributed to an increase in CO₂ in Australia. This outcome complies with the study of Awosusi et al. (2020) for Brazil, Bekun et al. (2021) for Indonesia, Udemba et al. (2021) for India, and Adebayo et al. (2021) for South Korea, who established a positive linkage between CO₂ emissions and GDP.

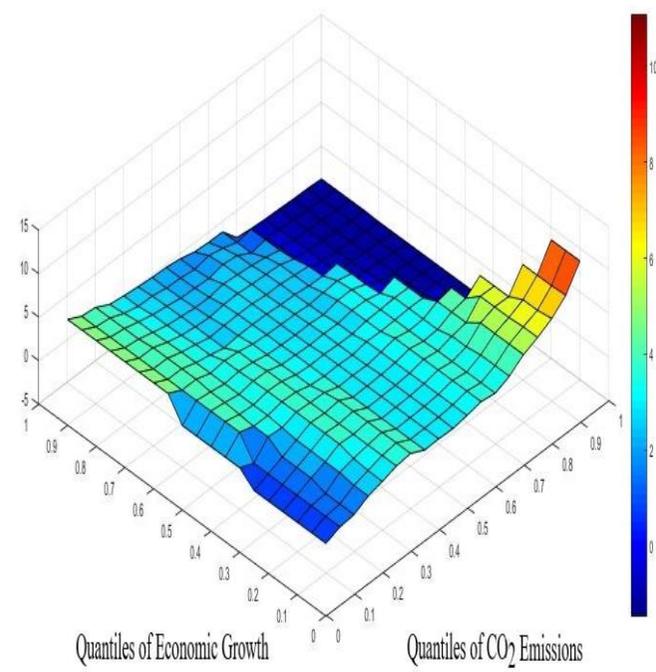
Figure 3c reveals the influence of COAL on CO₂ in Australia. The coefficient of the slope ranges from -0.2 to 1.4. The impact of COAL on CO₂ is positive and weak at most of the combination of quantiles of COAL and quantiles of CO₂ emissions; however, there is evidence of a strong positive effect of COAL on CO₂ in the high quantiles (0.8–0.95) of COAL and low quantiles (0.1–0.3) of CO₂ emissions. On the other hand, Figure 3d presents the influence of CO₂ on COAL. In all quantiles of CO₂ and COAL (0.1–0.95), the effect of CO₂ on COAL is positive; nevertheless, the effect of CO₂ on COAL is positive and stronger in the middle quantiles of both CO₂ and COAL. In summary, there is a positive feedback effect between CO₂ and COAL in Australia. These outcomes are not surprising since coal consumption (29.1%) constitutes a big chunk of Australia's energy mix. This outcome is consistent with the findings of Oluwajana et al. (2021) for South Africa, Pata (2018) for Turkey, and Lin et al. (2018) for China.

Figure 3e shows the effect of globalization on CO₂ in Australia. The coefficient of the slope ranges from 0.2 to 0.7. In all quantiles (0.1-0.95) of GLO and CO₂, the influence of GLO on CO₂ is positive. Nonetheless, in the middle and higher quantiles (0.4-0.95) of GLO and CO₂, the positive effect of GLO on CO₂ is more pronounced. Also, the effect of CO₂ on GLO is depicted in Figure 3f. The coefficient of the slope ranges from 0 to 2.5. The effect of CO₂ on GLO is positive at all quantiles of CO₂ and GLO; however, in the higher quantiles (0.75-0.95) of CO₂ and lower quantiles (0.1-0.3), the positive effect of CO₂ on GLO is stronger. The possible explanation for globalization's positive impact on CO₂ is that it increased trade increases overall factor productivity due to globalization. Foreign direct investment (FDI) and the transition of advanced technologies between industrialized and developing economies fuel economic growth. Furthermore, the globalization trend creates investment prospects via FDI and strengthens capital markets via financial liberalization. Undoubtedly, this mechanism boosts capital markets, commerce, and economic development, resulting in increased energy demand and, as a result, environmental deterioration. According to Kirikkaleli et al. (2020), globalization triggers a gradual increase in CO₂ due to the intensive use of resources to manufacture and use goods and services in industrialized and developing economies. This outcome complies with the findings of Kirikkaleli et al. (2020) for Turkey, Saint Akadiri et al. (2019) for South Africa, Adebayo & Kirikkaleli (2021) for Japan, and Le & Ozturk (2020) for seven (7) emerging nations who established a positive connection between globalization and CO₂ emissions.

3a. Effect of GDP on CO₂

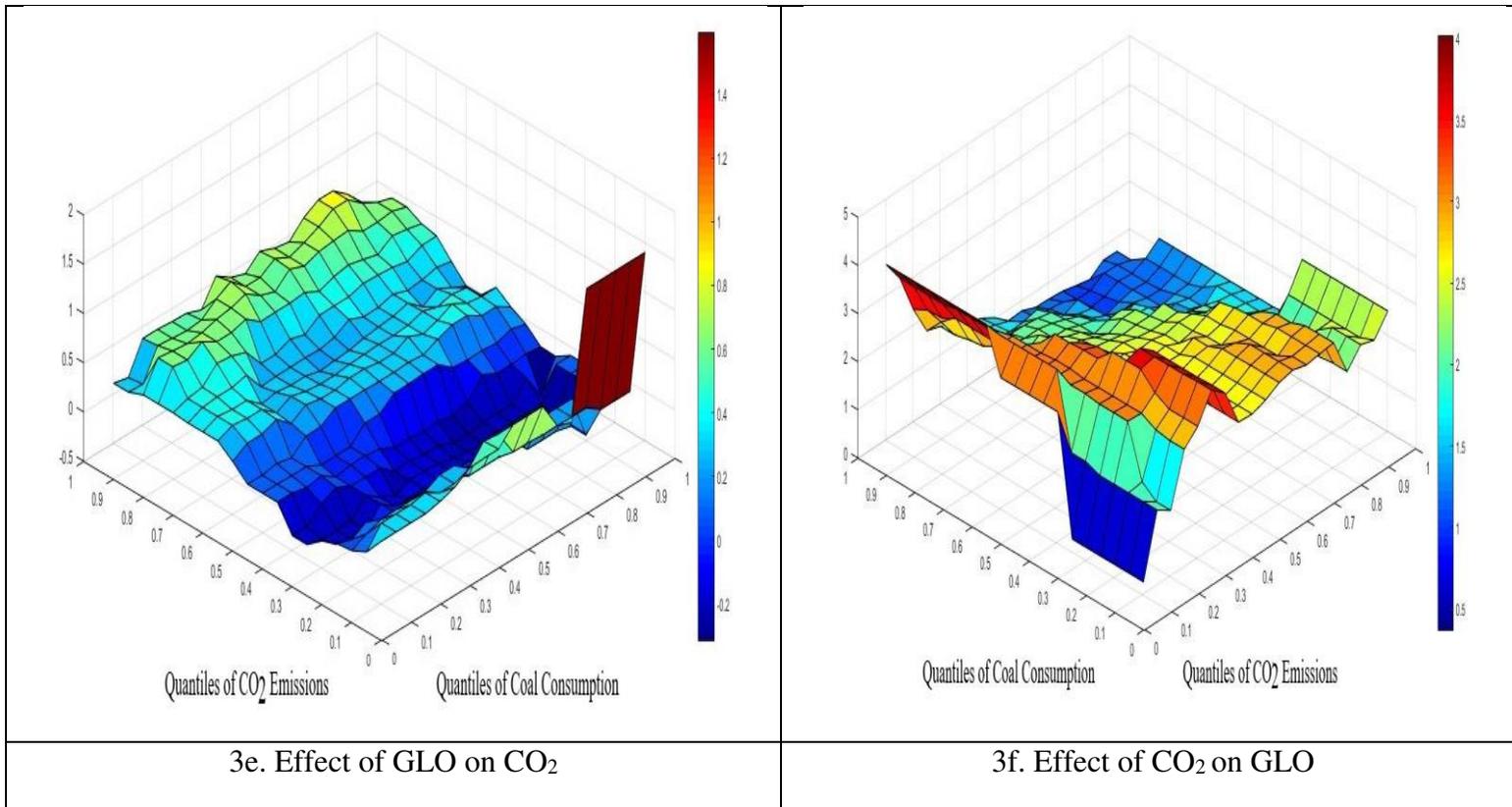


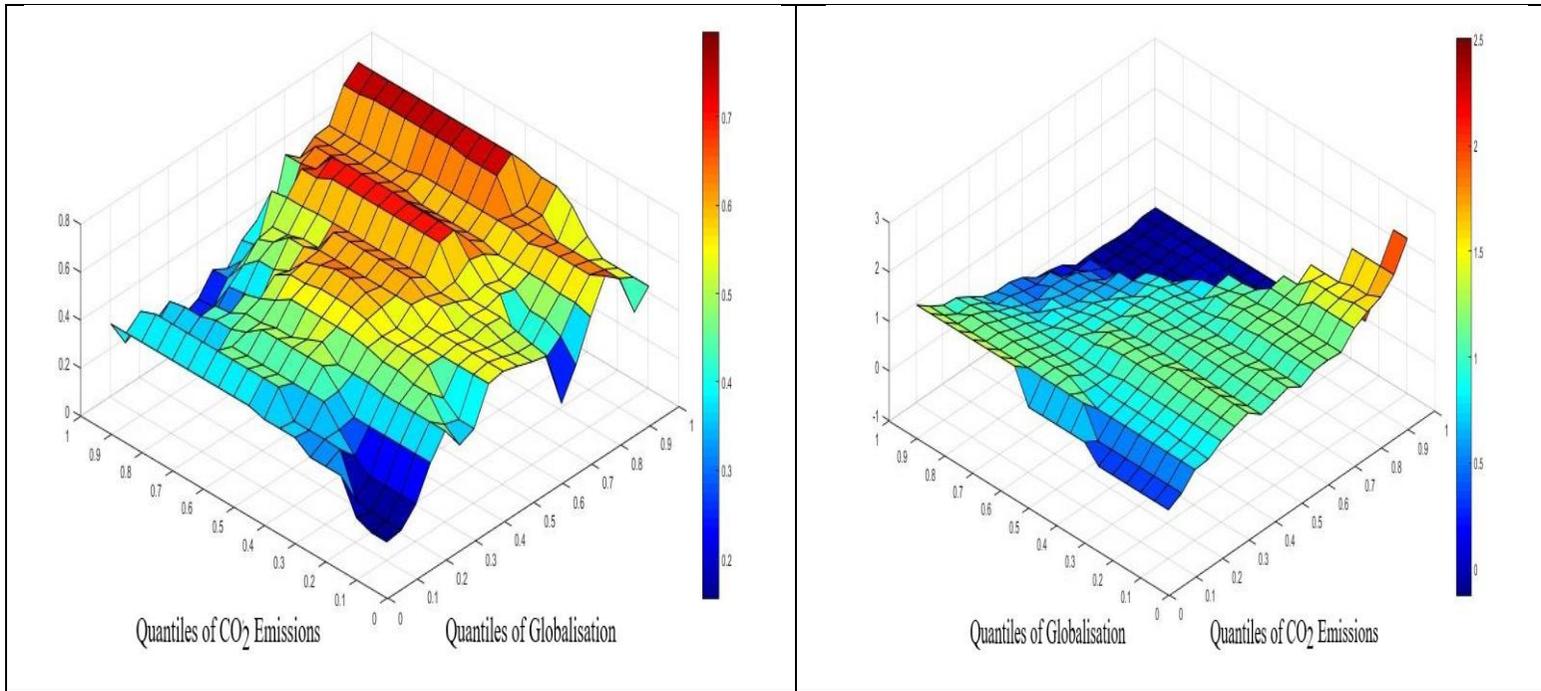
3b. Effect of CO₂ on GDP



3c. Effect of Coal on CO₂

3d. Effect of CO₂ on Coal





4.3. Robustness check for QQ approach

The QQ methodology can be conceived as a decomposition procedure for the traditional QR model's estimates, allowing for precise estimates for various quantiles of the dependent variable. The QR model used in this analysis is focused on regressing the θ th quantile of Y on X, so the quantile regression parameters are only indexed by θ . That being said, since the QQ analysis regresses the θ th quantile of Y on the quantile of X, the variables will be defined by both θ and τ , as previously mentioned. As a result, the QQ method provides more disaggregated details about the X–Y connection than the quantile regression model since the QQ method considers this relationship to be inherently heterogeneous through X quantiles. Given the QQ approach's inherent property of decomposition, the QQ estimates can be used to retrieve the traditional quantile regression estimates. The QQ parameters around τ can produce the QR parameters that are only indexed by θ . For instance, the coefficient of the QR model slope, which is denoted by $\gamma_1(\theta)$, is utilized to calculate the influence of X on Y, as follows:

$$\gamma_1 \equiv \overline{\widehat{\beta}_1(\theta)} = \frac{1}{S} \sum_{\tau} \widehat{\beta}_1(\theta, \tau) \quad (6)$$

Where $S = 19$ is quantiles number and $\tau = [0.05, 0.10, \dots, 0.95]$ is taken into consideration.

The graphs in Figure 4(a–f) show that irrespective of the quantile chosen, the averaged QQ estimates of the slope coefficient are comparable to the QR estimates for Australia. This graphical proof revealed that the main characteristics of the QR model could be retrieved by illustrating the more extensive details found in the QQ estimates, including a clear justification of the QQ approach. Thus, Figure 4a affirms the outcomes of the QQ analysis reported above. The outcomes of the QR disclosed that at all quantiles, the impact of GDP on CO₂ pollution is positive, which is consistent with the QQ regression outcome. On the flip side, Figure 4b illustrates that the QR results are consistent with the QQ results, demonstrating that CO₂ emissions positively influence economic growth. Furthermore, in Figure 4c, the outcomes of the QR disclosed that COAL influences CO₂ positively at all quantiles, which are in accordance with the findings of the QQ. On the other side, in figure 4d, the influence of CO₂ on COAL is positive at all quantiles, as revealed by both QR and QQ outcomes. This result illustrates that the QR and QQ outcomes validate each other. Also, in figure 4e, the influence of globalization on CO₂ emissions is positive at all quantiles, as revealed by the results from QR and QQ estimators. In figure 4f, the effect of CO₂ emissions on globalization is positive at all quantiles,

as shown by QR. This outcome complies with QQ outcomes reported earlier. In summary, the outcomes of the QR validate the results of QQ as indicated in Figure 4(a-f).

Figure 4a: Effect of GDP on CO₂

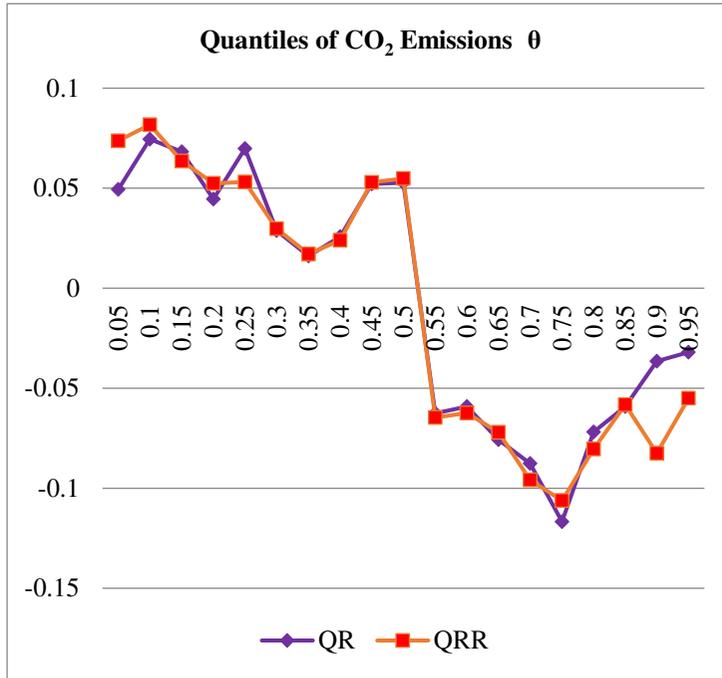


Figure 4c: Effect of Coal on CO₂

Figure 4b: Effect of CO₂ on GDP

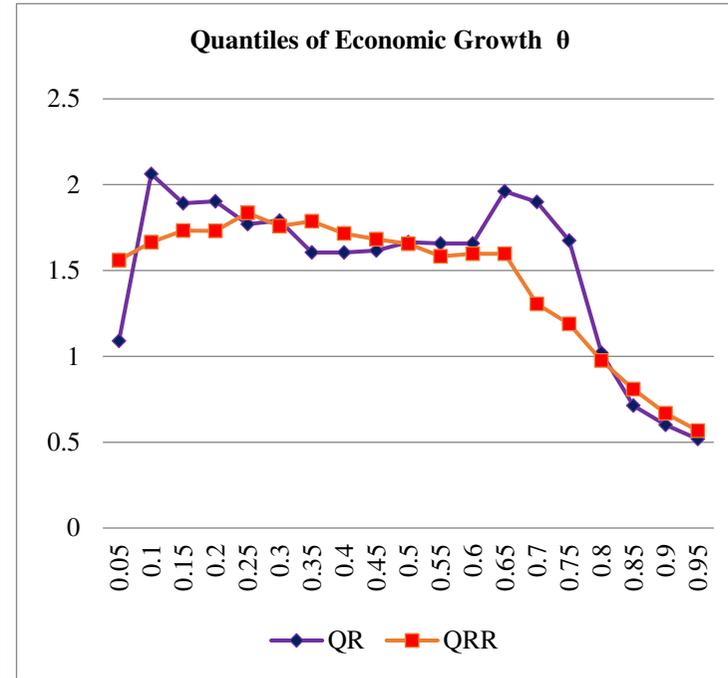
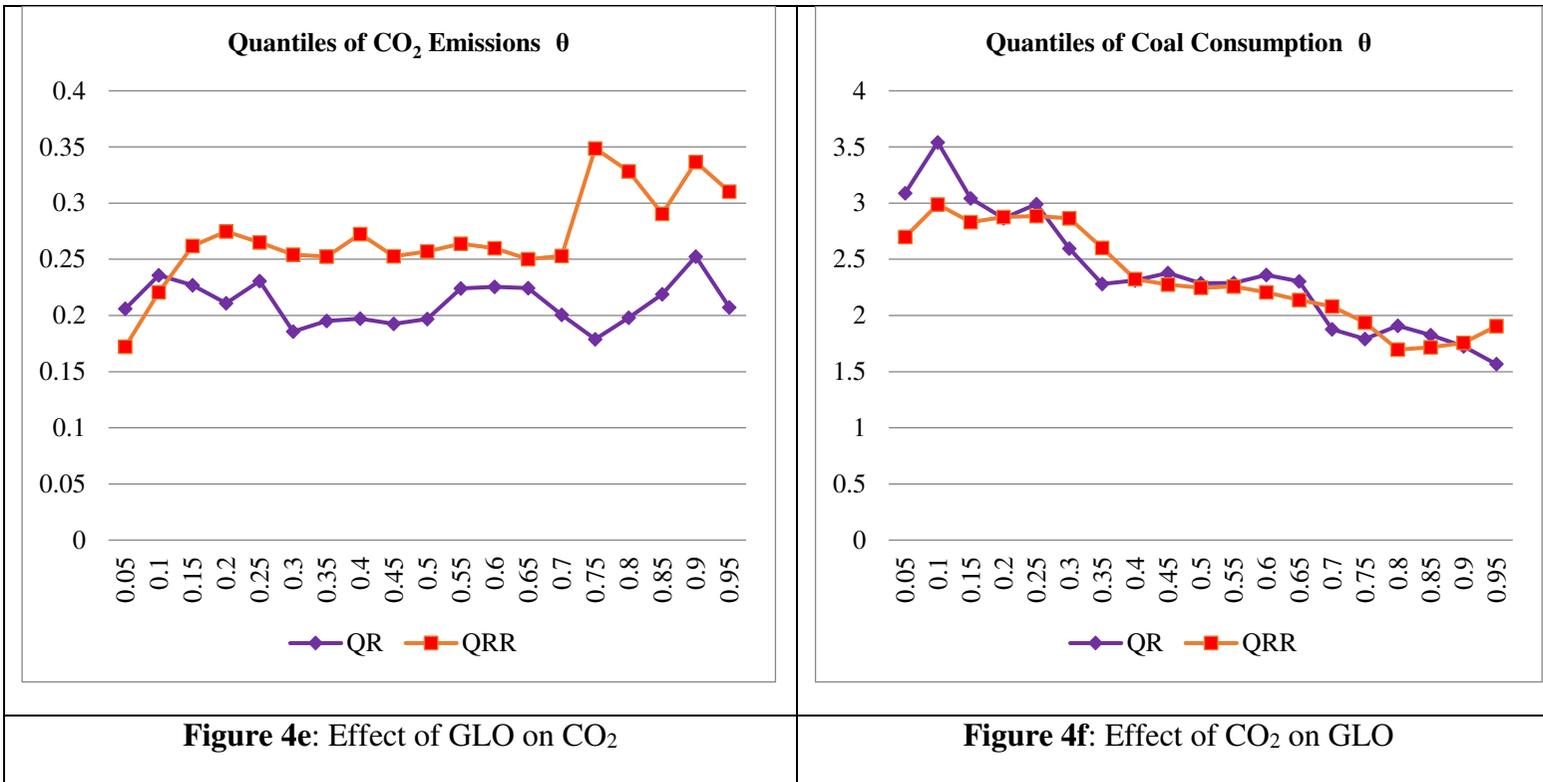
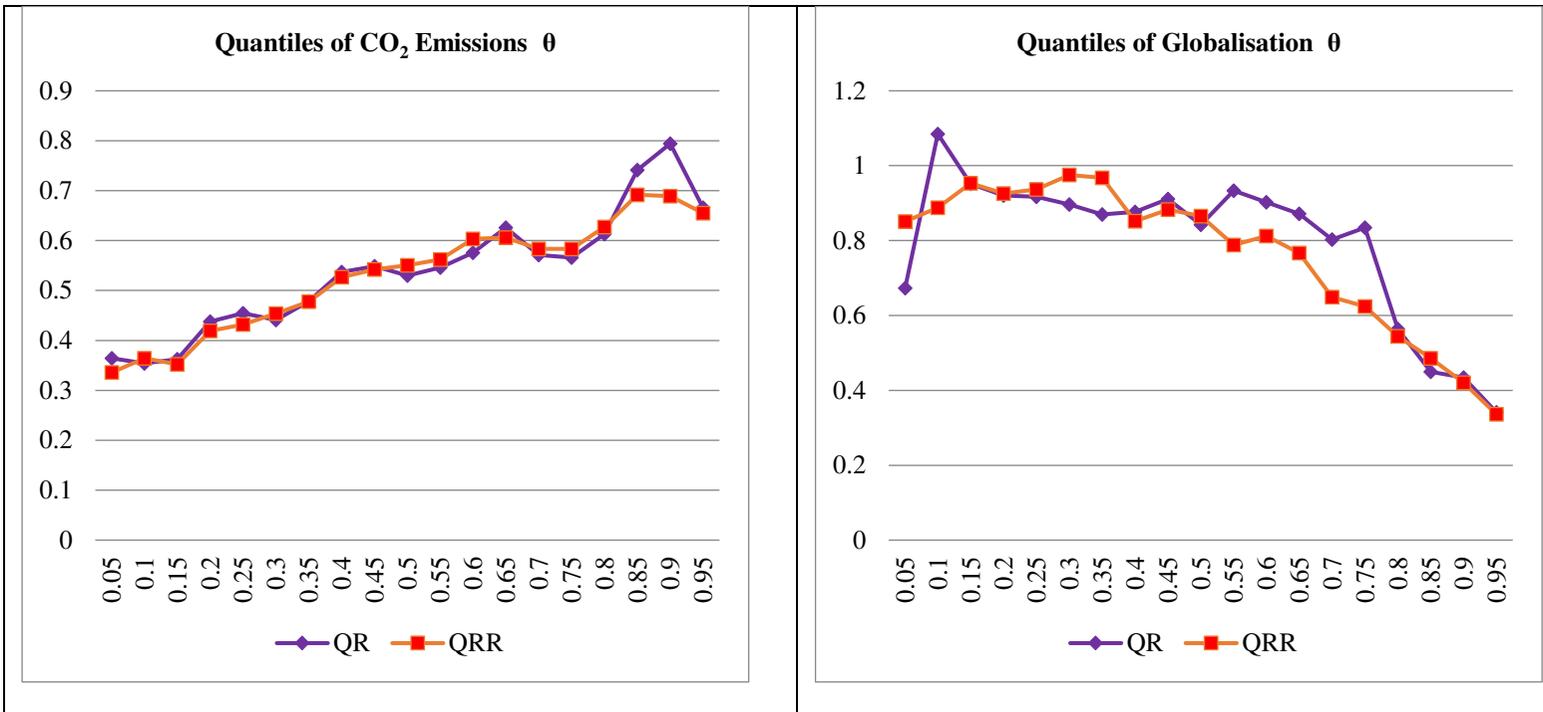


Figure 4d: Effect of Coal on CO₂





5. Conclusion and policy implications

The current paper applied newly developed econometrics techniques to explore the interconnection between CO₂ emissions, coal consumption, globalization and GDP in Australia using data spanning 1970 and 2018. Utilizing the novel QQ method, the current paper contributes to the ongoing literature and policy discussions on the relationships between carbon emissions, globalization, coal consumption and economic growth. Unlike conventional techniques, including OLS or quantile regression, the QQ approach helps one approximate how the quantiles of independent variable impact the quantiles of the dependent variable, thereby offering a more detailed explanation of the overall dependency structure between CO₂ emission and the regressors. To the authors' understanding, no prior study has examined these associations utilizing the novel QQ method. As an initial test, the study examines the linearity of the variables under investigation by employing the BDS test. The results from the BDS suggested that using the linear techniques will yield a misleading result, making the application of non-linear or nonparametric techniques such as the QQ approach crucial for this study. Furthermore, the outcomes of the QQ regression illustrated: (i) a positive feedback linkage between GDP and CO₂ emissions at most of the quantiles; (ii) a positive feedback linkage between globalization and CO₂ emissions at all quantiles; and (iii) a positive feedback interconnection between CO₂ pollution and coal consumption at all quantiles. As a robustness check, we employed the quantile regression (QR) test, and the results from QR are consistent with the findings from QQ.

The findings suggest that policymakers need to consider economic globalization in designing and implementing climate change policies for achieving the net-zero emissions target. Thus, given that economic globalization worsens carbon emissions at all quantiles, policymakers in Australia should not underestimate economic globalization on climate change and should be incorporated in designing and implementing an environmental sustainability policy framework. Failure to integrate economic globalization in carbon emissions forecasting models and environmental policies could impede Australia efforts for achieving the net-zero emissions target. The study also suggests that coal consumption has been driving Australia's carbon emissions. Australia uses coal to drive its economic growth but comes at the expense of deteriorating environmental quality. Australia total energy mix has been dominated by fossil energy; therefore, mitigating the negative environmental effect associated with coal consumption requires policymakers to fast-track Australia transition towards renewable energy use. In doing so, it is recommended that the Australian government should subsidize and

increase its budget allocation for financing renewable energy technologies. Finally, the study revealed that there is a positive feedback relationship between economic growth and carbon emissions. Thus, increasing economic growth induces higher economic growth while mitigating carbon emissions can cause a decline in the country's economic growth. Therefore, it is recommended that policymakers in Australia be cautious in designing and implementing its climate change policies without causing closed-form relationships that can cause a decline in the country's economic growth.

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