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R&D Investment, Financial and Environmental Performance Nexuses via Bootstrap Fourier Quantiles Granger Causality Test

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Abstract: This study investigated the relationship between R&D investments and financial and environmental performance. The direction, size, and significance of various phases of these variables were generated using the bootstrap Fourier quantiles Granger causality test. In our results, a positive relationship between R&D investment and CO_2 emission reductions was found at two tails of quantiles. Additionally, we observed a significantly positive relationship between financial performance and CO_2 emission reductions at the 0.5 quantile and above. The correlation between R&D investment and financial performance was identified to be positive under the 0.3, 0.4, 0.5 and 0.9 quantiles and negative under the 0.5 and 0.6 quantiles. The changing linkages among R&D investment, environmental performance and financial performance found in this study provide important information for policy makers, aiding in the development of R&D strategies to upgrade financial and environmental performance simultaneously.

Keywords: environmental performance; financial performance; R&D; bootstrap Fourier quantiles Granger causality test

1. Introduction

When considering the influence of CO_2 emissions on global warming, it is usually accepted that firms play a key role in emitting high levels of air contaminants through the manufacturing process (Busch and Hoffmann 2011). Widespread social concerns about this issue have pushed firms to find out ways of reducing their CO_2 emissions. Nevertheless, firms have encountered ostensible dilemmas relating to potential advantages and disadvantages. On the one hand, decreasing CO_2 emissions may not only create a cost burden for firms, but may also be harmful to competitiveness; on the other hand, it may save costs and improve efficiency (Hart and Ahuja 1996). Thus, the basic issue currently facing firms is how to develop strategies to upgrade firms' environmental performance (FEP) as well as financial performance (FFP) simultaneously.

Moreover, innovation is a strategy, i.e., several firms have lowered CO_2 emissions, upgraded competitiveness and improved FFP concurrently (Triguero et al. 2013). For this reason, this innovation is a key outcome of firms' research and development (R&D) investments; R&D investment has a positive influence on FFP simultaneously (Scarpellini et al. 2019; Duque-Grisales et al. 2020; Ezhilarasi and Kabra 2020). Relevant green R&D investment not only reduces CO_2 emissions, upgrading FEP (Samsul et al. 2019), it also improves FFP (Lee and Min 2015) and firm value (Ganda 2018). In summary, previous studies conclude that the greater the R&D investment, the greater the CO_2 emission reduction (better FEP). However, Duque-Grisales et al. (2020) state that green R&D investment is not associated with better FFP.

Additionally, prior studies have focused on how FEP responds to FFP, using CO_2 emissions as a proxy for FEP with respect to corporate social responsibility. Several studies have revealed the negative nexus between CO_2 emissions (FEP) and FFP (Liu et al. 2017; Moneva and Ortas 2010; Clarkson et al. 2011; Gallego-Álvarez et al. 2015), especially

during the pre-financial crisis period (Muhammad et al. 2015). Other studies have revealed negative associations between CO_2 emission and firm value (Saka and Oshika 2014; Matsumura et al. 2013). However, several studies have disclosed a negative nexus between FEP and FFP (Liang and Liu 2017) or firm value (Chang 2015). Others have found no such relationships (Lucato et al. 2017), including during the financial crisis (Muhammad et al. 2015). In addition, some have investigated the causal nexus between FEP and FFP; Endrikat et al. (2014) have shown not only that this causal direction might be reversed, i.e., from FFP to FEP, but also that this nexus is positive and partially bidirectional. Hence, to date, relevant studies of the relationship between FEP and FFP have not reached consistent conclusions.

This study examined the nexus between R&D investment, FEP (CO_2 emissions) and FFP in Taiwan using a novel bootstrap Fourier quantiles Granger causality test (BFQGCT) and data from 2005 to 2018. To date, this BFQGCT study is the first to provide a deep analysis of the influence of direction and size, as well as their significance in various phases of these trivariate relations. The empirical results show that the greater the R&D investment, the greater the CO_2 emission reduction under 0.2, 0.3, 0.7, 0.8 and 0.9 quantiles, separately; meanwhile, the greater the reduction in CO_2 emissions, the better the FFP under 0.5, 0.6, 0.8 and 0.9 quantiles; the more R&D investment, the better the FFP under 0.3, 0.4, 0.5 and 0.9 quantiles, respectively; moreover, the better the FFP, the less R&D investment under 0.5 and 0.6 quantiles, individually. Hence, understanding the causality nexus, as well as pathways among R&D investment, FEP and FFP, may have special significance for policy makers, helping to understand how R&D strategies can upgrade FEP and FFP concurrently.

This study is organized as follows: The next section discusses the literature review. The subsequent section proposes the new bootstrap Fourier quantiles Granger causality test. We then describe the data used in the study; then, the empirical results are offered. The last section contains the proposals and conclusions of this study.

2. Literature Review

Despite the huge number of studies regarding the R&D investment–FEP–FFP nexus for various countries over various periods, varying outcomes continue to be observed and the whole picture remains unclear. The trivariable nexus is conventionally analyzed in three parts: R&D investment–FEP, R&D investment–FFP and FEP–FFP. For the first strand of the literature, Lee and Min (2015) indicate the influence of green R&D investment in eco-innovation with regard to FEP and FFP in Japanese manufacturing between 2001 and 2010, finding a negative nexus between CO_2 emissions and green R&D, although the latter was positively associated with FFP. Using firm-level data from G6 countries between 2004 and 2016, Samsul et al. (2019) showed that R&D investment upgrades FEP. Utilizing data from 181 technology-industry firms in Taiwan, Huang and Wu (2010) reveal that FEP in green commodity initiatives displayed a positive influence on FFP. Examining the nexus between FFP and green initiatives, as well as FEP, Chen et al. (2018) found that green initiatives displayed a positive effect upon green FEP, which in turn exerted a positive influence on FFP. Nevertheless, the influence of green initiatives varies by nation. Firms in Canada, as well as European nations, have linked green initiatives and FEP, as well as in Japan and USA. Hong Kong and China lag behind compared to other nations. Tariq et al. (2019) found that the higher the green commodity innovation performance, the higher the FFP in Thai manufacturing firms.

Several pieces of empirical evidence of a nexus between R&D investment and FFP exist. Lin (2017) found that R&D investment has a positive link with a firm's value in a study of firms engaging in social responsibility in Taiwan. Ganda (2018) reported a positive nexus between Green R&D and firm value in an analysis of 14 South African mining companies. Analyzing green patents and R&D intensity, with the aim of discovering the factors leading to successful eco-innovation procedures in Spain and in the EU, Scarpellini et al. (2019) proposed a positive nexus between eco-innovation activity and R&D intensity in firms. Meanwhile, relevant results show the impact of implementing

innovation on FFP. Ezhilarasi and Kabra (2020) found that R&D investment has a positive influence on FFP. Duque-Grisales et al. (2020) reported that a positive moderating effect of R&D investment on the nexus between FFP and green innovation was exhibited in firms with increasing R&D investments, analyzing 86 listed firms in emerging transnational markets in Latin America.

Some studies have specified whether it pays to be green, thus concentrating on the nexus between FEP and FFP. Clarkson et al. (2011) addressed the question "Does it pay to be green?" among the four most polluting industries in the US, showing that firms which upgraded their FEP in the previous period resulted in improving their FFP in the following periods. Busch and Hoffmann (2011) reported that when using CO_2 emissions as an outcome-based approach, FEP pays off. Contrarily, using CO_2 control according to a procedure-based method, they observed a negative nexus between the FEP and FFP among the 2500 biggest firms by market capitalization in the Dow Jones Global Index. Matsumura et al. (2013) indicated that on average, for each extra million kilograms of CO_2 emissions, company value is reduced by USD 212,000 for S&P 500 corporations. A negative nexus between CO_2 emissions and FFP was found to exist in the UK (Liu et al. 2017) for 89 international firms (Gallego-Álvarez et al. 2015) during the pre-financial crisis period (Muhammad et al. 2015). Molina-Azorín et al. (2009) reviewed 32 studies to examine the influence of FEP on FFP. The results were varied, but studies in which a positive impact of FEP on FFP was found were dominant. Buysse and Verbeke (2003) reported that an environmental leadership approach is linked with an increase in FFP for Belgium-based companies, but not for affiliates of foreign multinational enterprises.

Several studies have evaluated the nexus between FEP and environmental disclosure, studying whether investors consider the significance and value of FEP information when making investment decisions. Dilla et al. (2019) showed that FEP, as well as assurances regarding relevant FEP information, had a high effect on investors' investing decisions, with sturdy environmental responsibility opinions. DiSegni et al. (2015) compared the FFP in all the US companies included in the Dow Jones Sustainability Indices and proposed that corporations with strong social responsibility and environmental sustainability are categorized by importantly larger profit measures than the corresponding industries and firms. Wingard and Vorster (2001) reported a positive nexus between FFP and firm environmental responsibility with respect to South African recorded firms, i.e., the higher the level of a firm's environmental responsibility, the better its FFP. Longoni and Cagliano (2018) offered empirical support for the influence of comprehensive environmental disclosure practices in relation to FFP but found no nexus with respect to the effect on FEP. Nevertheless, Deswanto and Siregar (2018) showed that FFP has no effect on firm environmental disclosures. Moreover, they argued that lagging FEP indicates a positive influence with respect to firm environmental disclosures, concluding that environmental disclosures by firms have no effect on the firm's market value and do not arbitrate the influence of FEP and FFP regarding firm value in Indonesia. Testa and D'Amato (2017) studied the bidirectional causal nexus between FFP and firm environmental responsibility regarding the listed manufacturing company data in Italy from 2005 to 2014. Meanwhile, their outcomes showed no support for the bidirectional hypothesis; however, firm environmental responsibility had a significant relationship with previous FFP, supporting the slack resources hypothesis. Giannarakis et al. (2017) studied the influence of FEP with respect to the environmental disclosure level of Standard and Poor's 500 firms, and their relevant results showed that higher pollution levels regarding greenhouse gas emissions had a negative effect on the distribution of carbon disclosure information, which suggests a positive nexus between a firm's environmental disclosure level and its FEP. In addition, Alipour et al. (2019) indicated that there was a significant positive nexus between FFP and environmental disclosure quality in Iranian firms.

Muhammad et al. (2015) found no connection between FEP and FFP from 2008 to 2010 (during the financial crisis) in Australia. Liang and Liu (2017) obtained the same result for Chinese firms. Based on a comprehensive meta-analysis of 149 stud-

ies, Endrikat et al. (2014) showed a positive and partly bidirectional nexus between FEP and FFP. Laguir et al. (2018) demonstrated a bidirectional nexus between FEP and FFP for French banks. Yu et al. (2009) made use of correlation analysis with data from of 51 European firms in 14 industries across 15 countries for the purpose of investigating the possible nexus between FFP and FEP; finding no positive nexus between FFP and FEP. Dragomir (2010) reported no nexus between FFP and FEP based on data from 60 of the biggest European Union industry commercial units. To date, the academic debate concerning the nexus between R&D investment, FEP (CO_2 emission) and FFP is ongoing.

3. Methodology

3.1. Empirical Model

Despite the causality specification of the Granger causality test (GCT, Granger 1969), which is unable to offer knowledge regarding nonlinear causalities or a tail causal relation, the quantile causality method analyzes causal nexuses in a more agile and careful way. In this study, the quantile regression Fourier Toda–Yamamoto (QRFT-Y) GCT proposed by Nazlioglu et al. (2016) is used to test the relations among R&D investment, CO_2 emissions and ROA in Taiwan. Via the QRFT-Y GCT, the subsequent Fourier series is used in lieu of utilizing dummy parameters to cogitate the structural breaks in the causal nexus. Gallant (1981) and Gallant and Souza (1991) indicate that a small number of low-frequency units for a Fourier function are able to catch an unidentified number of breaks regarding sharp as well as gradual structural breaks:

$$d(t) = \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) \tag{1}$$

This Fourier series, in which k specifies the frequency, can be incorporated into the testing equation; its quantile approach is defined as follows:

$$\Delta Y_t(\tau) = c(\tau) + d(t) + \sum_{i=1}^{p-1} \theta(\tau)\Delta Y_{t-i} + \sum_{i=1}^{p-1} \delta(\tau)\Delta X_{t-i} + \sum_{i=1}^{p-1} r(\tau)\Delta Z_{t-i} + \varepsilon_t \tag{2}$$

or

$$\begin{aligned}
\Delta Y_t(\tau) &= c + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{p-1} \theta(\tau)\Delta Y_{t-i} \\
&\quad + \sum_{i=1}^{p-1} \delta(\tau)\Delta X_{t-i} + \sum_{i=1}^{p-1} r(\tau)\Delta Z_{t-i} + \varepsilon_t
\end{aligned} \tag{3}$$

where x, y and z are R&D investment, CO_2 emissions and ROA, respectively. The GCT can be simulated from $z{\rightarrow}y$ at various quantiles regarding the null hypothesis of $\gamma(\tau_i) = 0$ for $i = 1, 2, \ldots, p$. Moreover, the null hypothesis without Granger causality, i.e., $R\beta(\tau) = 0$, is simulated as follows:

$$\text{Wald} = (R\beta(\tau))' \left[R(Z'Z)^{-1} \otimes S \right] R')^{-1}](R\beta(\tau)) \tag{4}$$

where R defines the indicator matrix of these variables (constrained variables denoted by ones), $\beta(\tau)$ denotes D' column stack, S represents the variance–covariance matrix for the unconstrained approach; $\otimes$ indicates the Kronecker product. Furthermore, considering that Hatemi-J and Uddin (2012) mention the fact that conditional heteroskedasticity (ARCH) influences exist in the data, and these do not usually abide by normal distribution; there is thus a probability that the Wald statistic distribution will significantly diverge from its asymptotic distribution. Hence, the bootstrapping simulation technique, using 10,000 iterations, proposed by Hatemi-J and Uddin (2012), is used to comprise the 1%, 5% and 10% critical values from the empirical distribution. Similarly, the Wald test can be utilized for testing of the null hypothesis: $\gamma(\tau_i) = 0$ for $i = 1, 2$.

3.2. Data

In this study, Taiwan Stock Exchange (TSE)-listed firms were used for sample data, obtained from the Taiwan Economic Journal (TEJ) database. Although the initial sample started with 2640 firm-year observations (542 firms) that were involved with CO_2 emissions, as stated in their financial reports from 2005 to 2018, up to 1097 of these (222 firms) were excluded, owing to 430 of them (90 firms) having missing accounting and financial data, and 667 (132 firms) having zero R&D investment, respectively. Thus, the final unbalanced panel data comprised 1543 firm-year observations (320 firms) from 2005 to 2018, covering the financial crisis (from 2007 to 2009) period.

These are cross-sectional and time-series data, permitting the overall examination of the trivariable nexus. This study's parameters were defined as follows. The CO_2 emissions were evaluated as the ratio of CO_2 emissions to assets in order to minimize heterogeneity problem which arises from different sizes. The return on assets (ROA) was evaluated as the ratio of net profit to assets. R&D was measured as the ratio of R&D investment to net sales revenue. Following Scarpellini et al. (2019), we used R&D investment as a metric for the measurement of innovation, and CO_2 emissions and ROA served as a proxy for FEP and FFP, respectively.

Table 1 presents the descriptive statistics for the unbalanced panel sample from 2005 to 2018. The total number of firms was 320, and there were 1543 firm-year observations. Jarque–Bera analysis showed that CO_2 emissions, ROA and R&D were non-normally distributed. The mean (median) value of CO_2 emission (divided by assets) was 0.1092 (0.0214), with a maximum value of 4.0409. The mean (median) value of ROA was 10.39072 (9.7600), with a maximum value of 55.64. The mean (median) value of R&D was 0.088068 (0.023), with a maximum value of 17.68196.

Table 1. Descriptive Statistics.

	Mean	Medium	Max.	Min.	Std.Dev.	Skewness	Kurtosis	Jarque–Bera
CO_2	0.1092702	0.021471	4.0409	0.0000031	0.33829	7.204648	64.13949	253,673.3 ***
ROA	10.39072	9.760000	55.640	−63.04000	8.286528	−0.479822	10.49469	3670.491 ***
R&D	0.088068	0.023018	17.68196	2.39×10^{-5}	0.778212	18.77636	375.0439	8,989,701 ***

Notes: *** indicates significance at the 1% level. CO_2 indicates the ratio of carbon emission to assets, used in order to minimize the heterogeneity problem which arises from different sizes. ROA refers to the ratio of net profit to assets and R&D refers to the ratio of R&D investment to net sales revenue.

4. Empirical Results

Using a novel bootstrap Fourier quantiles Granger causality test to analyze data from 2005 to 2018, this study examines the nexus between R&D investment, FEP (CO_2 emissions) and FFP (ROA) in Taiwan. First, we carried out traditional unit root tests, followed by the test of bootstrap Fourier Granger causality in quantiles.

4.1. Unit Root Test Results

Numerous traditional unit root tests the ADF, PP and KPSS tests were applied and the outcomes are shown in Table 2. Only R&D was non-stationary, and this became stationary at level (I (0)) and after taking the first difference. CO_2 emissions and ROA were all stationary at level (I (0)) and after taking the first difference, respectively.

Table 2. Unit Root Test Results.

	Level			First Difference		
	ADF	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**
CO_2	−7.824175 ***	−11.63009 ***	0.372556	−12.97932 ***	−60.37167 ***	0.079667
ROA	−18.57293 ***	−23.46197 ***	0.242253	−23.46197 ***	−146.3223 ***	0.077861
R&D	−11.174 ***	−6.88788 ***	−50.16287 ***	−18.71048	−50.16287 ***	0.116063

Notes: *** indicates significance at the 1%, 5% and 10% levels, separately. CO_2, refers to the ratio of carbon emission to assets, used to minimize the heterogeneity problem which arises from different sizes. ROA refers to the ratio of net profit to assets and R&D refers to the ratio of R&D investment to net sales revenue.

4.2. Bootstrap Fourier Quantiles Granger Causality Test

To test the Granger causality, the existence of a Fourier expansion in equation (2) is tested using the conventional Wald test. The critical values are computed, using the bootstrapping procedure, with 10,000 replications. In Table 3, the BFQGCT results, running from R&D to CO_2 emissions, indicate that the values of the Wald statistics equal 4040.917, 1748.515, 14,956.70, 2048.546 and 1334.683 under 0.2, 0.3, 0.7, 0.8 and 0.9 quantiles, respectively, and each is greater than its bootstrap critical values at 5% or 1%. The results indicate that the null hypothesis of $\gamma\_1 = \gamma\_2 = 0$ can be strongly rejected at 5% or 1% levels of significance. There is a one-way Granger causality running from R&D investment to CO_2 emissions (under 0.2, 0.3, 0.7, 0.8 and 0.9 quantiles). By observing the symbol of the independent-variable coefficients, it can be seen that R&D investment causes CO_2 emissions to decrease. These findings demonstrate that R&D investment (innovation) reduces CO_2 emissions (increasing environmental performance) under 0.2, 0.3, 0.7 and 0.8 environment performance quantiles, respectively. The Granger causality running from CO_2 emissions to R&D is insignificant.

Table 3. Quantile Granger causality test among CO_2 emissions, ROA and R&D.

Quantile		Wald Test	CV 10%	CV 5%	CV 1%
	0.1	2.137394	579.4584	1226.427	4204.114
	0.2	4048.917 **	581.3760	1164.403	4586.895
	0.3	1748.515 **	447.0656	853.5995	3288.686
R&D→CO_2	0.4	11.50215	375.8133	645.3720	2315.774
(negative)	0.5	6.815864	393.0546	637.7543	1860.990
	0.6	3.146628	458.4620	752.7757	3216.239
	0.7	14,956.70 **	595.3574	1025.499	4906.720
	0.8	2048.546 **	553.0080	1133.514	5111.547
	0.9	1334.683 **	367.9836	814.6717	3258.381
	0.1	3.880787	89.13272	125.0902	263.7421
	0.2	1.951739	36.83624	50.19736	87.53883
	0.3	1.069226	23.23389	30.37297	47.74848
	0.4	3.064328	20.97151	26.13679	41.64357
CO_2→R&D	0.5	7.655415	22.86247	28.58717	44.25323
	0.6	9.659755	29.81040	36.59088	57.44164
	0.7	2.334995	41.04957	50.95854	76.42753
	0.8	0.898962	65.85857	84.46474	136.1751
	0.9	3.004358	108.4133	147.1132	268.6119
	0.1	15.70273	65.06867	85.70210	145.4731
	0.2	2.602070	25.97153	35.32248	61.96993
	0.3	8.946593	15.69944	21.71965	38.12811
CO_2→ROA	0.4	7.295380	12.15180	16.66797	29.97618
(negative)	0.5	17.20173 **	12.27122	16.51336	28.73321
	0.6	27.32757 **	14.92517	19.52453	32.64043
	0.7	19.32699	21.67174	28.28871	46.05749
	0.8	57.70779 **	37.64852	48.66073	87.00708
	0.9	119.3797 **	77.38182	100.8456	174.9821
	0.1	0.532327	23.39925	27.08539	34.32783
	0.2	3.043201	16.08705	18.15568	22.78126
	0.3	3.958516	15.65950	17.73498	21.70123
	0.4	3.158619	15.99712	18.09925	22.31895
ROA→CO_2	0.5	2.501898	15.82778	17.92695	22.32631
	0.6	3.426661	16.38645	18.86070	24.30664
	0.7	6.121450	19.46645	22.38043	29.09297
	0.8	7.133838	27.26242	32.11197	41.93813
	0.9	32.68547	52.58201	64.05667	87.97280

Table 3. *Cont.*

Quantile		Wald Test	CV 10%	CV 5%	CV 1%
	0.1	341.3374	575.3449	663.1935	938.3257
	0.2	386.0742	445.2968	524.5006	754.4572
	0.3	411.8341 *	353.6841	422.8852	578.4530
R&D→ROA	0.4	397.0857 **	335.1044	386.8160	514.1024
(positive)	0.5	470.3310 **	322.8919	375.7900	486.7262
	0.6	148.1905	270.1801	340.4037	495.5135
	0.7	128.7050	379.8922	467.0425	679.6993
	0.8	370.8866	567.1032	672.3535	943.0788
	0.9	1289.359 **	849.3702	1020.328	1404.347
	0.1	3.043362	37.08690	44.13056	59.42251
	0.2	9.743216	22.38750	25.82377	33.62489
	0.3	15.85482	20.22187	23.12610	28.80851
ROA→R&D	0.4	18.23258	18.48369	20.93514	26.67804
(negative)	0.5	35.66072 ***	17.96496	20.67274	26.01630
	0.6	22.96598 **	18.95430	21.75916	27.86017
	0.7	7.064264	19.63218	22.91689	30.25602
	0.8	16.28614	25.96321	30.44414	41.30809
	0.9	24.86138	56.45294	66.90733	90.15367

Notes: The frequency of the data is monthly. CV10%, CV 5%, and CV1% are the critical values of statistical significance, individually. *, ** and *** indicate rejection at the 10%, 5% and 1% levels, individually.

Table 3 shows the results of the Granger causality test running from CO_2 emissions to ROA, indicating that the values of the Wald statistics equal 17.20173, 27.32757, 57.70779 and 119.3797 under 0.5, 0.6, 0.8 and 0.9 quantiles, respectively, and each is greater than its bootstrap critical values at 5%. The results indicate that the null hypothesis of $\gamma\_1 = \gamma\_2 = 0$ can be strongly rejected at the 5% level of significance. There is a one-way Granger causality running from CO_2 emissions (environmental performance) to ROA (financial performance) (under 0.5, 0.6, 0.8 and 0.9 quantiles). The symbol of the independent-variable coefficients indicates that CO_2 emissions cause ROA to decrease. This means that reducing emissions (increasing environmental performance) "Granger-causes" an increase financial performance under 0.5, 0.6 0.8 and 0.9 financial performance quantiles, respectively. The Granger causality running from ROA to CO_2 emissions is insignificant.

The Granger causality test running from R&D to ROA indicates that the values of the Wald statistics equal 411.8341, 397.0857, 470.3310 and 11,289.359 under 0.3, 0.4, 0.5, and 0.9, respectively, and each is greater than its bootstrap critical values at 10% or 5%. The outcomes show that the null hypothesis of $\gamma\_1 = \gamma\_2 = 0$ can be strongly rejected at the 10% or 5% level of significance. There is a one-way Granger causality running from R&D to ROA (under 0.3, 0.40, 0.5 and 0.9). By examining the symbol of the independent-variable coefficients, it can be seen that increasing R&D causes ROA to increase. These findings conclude that increasing R&D investment increases FFP under 0.3, 0.4, 0.5 and 0.9 financial performance quantiles, respectively.

The Granger causality test running from ROA to R&D indicates that the values of the Wald statistics equal 35.66072 and 22.96598 under 0.5 and 0.6, respectively, and each is greater than its bootstrap critical values at 1% and 5%. The outcomes show that the null hypothesis of $\gamma\_1 = \gamma\_2 = 0$ can be strongly rejected at the 1% and 5% level of significance. The Granger causality runs from ROA to R&D (under 0.5 and 0.6 quantiles). By examining the symbol of the independent-variable coefficients, it can be seen that increasing ROA causes R&D investment to decrease, i.e., the better the FFP, the lower the R&D investment under the middle R&D investment quantiles. The causality nexus, as well as the pathways among R&D investment, CO_2 emission and financial performance, are shown in Figure 1.
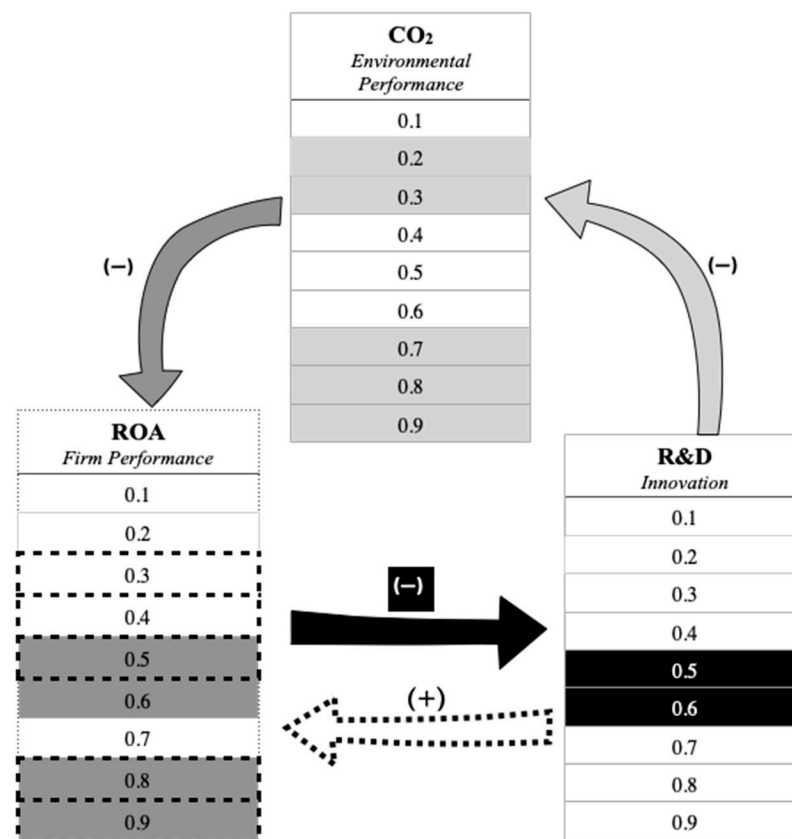
Figure 1. Quantile Granger Causality Test Direction.

5. Conclusions

As CO_2 emissions affect global warming, social concern about the environment is increasing. These increasing social concerns, along with the question of whether "it pays to be green" in business, have motivated firms to seek solutions in regard to decreasing CO_2 emissions and increasing profitability simultaneously. In this study, we have examined the nexus between R&D investment, FEP (CO_2 emissions) and FFP in Taiwan via a novel BFQGCT using data from 2005 to 2018. The empirical outcomes show that R&D investment causes an improvement in both CO_2 emissions and ROA. By examining the results of the independent-variable coefficients, it can be observed that R&D investment (innovation) reduces CO_2 emissions (boosting FEP) under 0.2, 0.3, 0.7, 0.8 and 0.9 FEP quantiles, separately, and R&D investment increases ROA (FFP) under 0.3, 0.4, 0.5 and 0.9 FFP quantiles, individually. Reducing CO_2 emissions (FEP) causes an increase in ROA (FFP) under 0.5, 0.6, 0.8 and 0.9 ROA quantiles, separately, and increasing ROA (FFP) causes reduced R&D investment under 0.5 and 0.6 quantiles, individually. Finally, increasing R&D causes an increase in ROA under 0.3, 0.40, 0.5 and 0.9 ROA quantiles, individually, in Taiwan.

Contrary to the findings of a previous study that used only mean coefficient analysis via the OLS method, the analyses presented here indicate that the greater the R&D investment, the greater the reduction in CO_2 emissions under 0.2, 0.3, 0.7, 0.8 and 0.9 environment performance quantiles, individually. In contrast with previous findings (Scarpellini et al. 2019; Duque-Grisales et al. 2020; Ezhilarasi and Kabra 2020), our results show that a larger R&D investment is linked with better financial performance under 0.3, 0.4, 0.5 and 0.9 quantiles, separately. The negative causality running from ROA to R&D under 0.5 and 0.6 R&D investment quantiles, individually, indicates that better financial performance is linked with the less R&D investment in middle R&D investment quantiles. These findings suggest that there is a negative causality running from environmental performance to financial performance under the 0.5, 0.6, 0.8 and 0.9 financial performance quantiles, individually, which offers a potential explanation for the inconclusive findings

in the previous literature (Liu et al. 2017; Moneva and Ortas 2010; Clarkson et al. 2011; Gallego-Álvarez et al. 2015; Muhammad et al. 2015). Understanding this causal nexus, as well as the pathways among R&D investment, CO_2 emission and financial performance, has special significance for policy makers intending to understand how R&D strategies can improve FEP and FFP simultaneously. This study is unique among prior studies in that it examines the direction and size of R&D investment, financial and environmental performance relations via a bootstrap Fourier quantiles Granger causality test. Due to the limitations of this model, it was not possible to analyze how the quantiles of the explanatory variables affected the conditional quantiles of the dependent variables. Further studies can hopefully make up for this limitation.

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