Advance Journal of Econometrics and Finance
Vol-4, Issue-1, 2026

Advance Journal of Econometrics and Finance

Online ISSN
2959-8990
Print ISSN
2959-8982
https://ajeaf.com/index.php/Journal/About

Name of Publisher: SCHOLAR CRAFT EDUCATION & RESEARCH HUB

Review Type: Double Blind Peer Review

Journal Frequency: Quarterly Research Journal

Corporate Environmental Accountability, Institutional Quality, And Trade Openness On Financial Performance: The Mediating Role Of Digital Transformation

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Abstract

This study focuses on how corporate environmental accountability, institutional quality, and trade openness affect financial performance of developed economies through digital transformation, which acts as a mediating variable. The study is based on a pooled Ordinary Least Squares (OLS), Fixed Effects (FE) and Random Effects (RE) estimates using a balanced panel dataset of 44 high-income economies with eight geographic regions aided across 2015-2024 in case of offering strong empirical evidence and internally consistency. The environmental accountability of the proxies CO_2-emission per capita is the proxy of the institutional quality of trade, the Rule of Law index, and the trade as a percentage of the GDP, the proxy of the trade openness. The mediators in digital transformation are fixed broadband subscriptions per 100 people and gross domestic savings as a percentage of GDP is financial performance. The suitability of the use of fixed effects with panel-corrected standard errors as an ideal specification is verified by diagnostic tests. The findings indicate that the CO2 emission would have a negative and substantial influence on financial performance with institutional quality and trade openness showing important positive outcomes. Imperatively, the digital transformation partially embodies all the three relationships as it acts as an amplification channel that boosts the institutional and trade returns to the accumulation of savings and at the same time combats the savings-degrading impacts of environmental degradation. The article appeals to the extant literature on environmental-economic performance studies to the macro-level panel setting and offers a practical policy advice to high-income economies in going through the two transitions, namely, decarbonization and digitalization.

Keywords: Environmental Accountability; CO2 Emissions; Institutional Quality; Rule of Law; Trade Openness; Digital Transformation; Financial Performance; Panel Data; Developed Economies

JEL Classification: Q53; K40; F14; O33; C23; G10

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1. Introduction

The nexus between environmental responsibility, institutional governance, and economic achievement has taken on increased policy urgency with the net-zero projects of the Paris Accords, the European Green Deal, and the increased understanding that high income economies need to simultaneously rapidly decarbonization and sustain the financial performance patterns necessary to finance the energy transition itself. The fiscal and financial implications of environmental culpability design flops are a qualitatively different group of problems to that faced by developed countries, which are typified by the high per capita portfolio of emissions, institutionalized structures and entitlement to global trading systems. The issue of how financial performance is determined by the joint nature of carbon-intensive economic structures, the quality of institutional governance, and the level of integration of trade is the main question of the current research.

The carbon dioxide per capita emissions best represent the direct linkage between environmental responsibility on a national scale, and the present environmental liability held by the national economies due to pursuing the fossil-fuel-based growth pattern. The high per capita CO2 emissions are warning not only of the present price of the environment but also the future influence on the budget by carbon pricing regimes, the waste of fossil fuel sectors, and the expenses to meet the requirements in the form of the environmental sustainability (ESG) frameworks (Carney, 2015; TCFD, 2017). Since advanced economies gradually internalize carbon externalities, as updated plans of emissions trading schemes, carbon border adjustments, required climate risks disclosed schemes, the financial performance cost of high-emission economic systems is becoming increasingly quantifiable, measurable at the national level.

Quality of institutions - institutional quality, a variable that in this case is measured using the Rule of Law index of the Worldwide Governance Indicators by the World Bank, represents how well the agents believe in the rules and follow them within the society such as the quality of the contract enforcement, protection of property rights, effectiveness of the police and courts, and the probability of crime and violence. Rule of law is not an institutional threshold position but rather a persistent source of the competitive advantage which defines the intensity of financial markets, quality of cross-border investment environment, and credibility of the long-term policy commitment such as sustainability framework by the developed economies. Effective rule of law institutions lower the transaction costs that weaken the financial returns to trade and investment, establish the credibility frame work on which green finance instruments rely and generate the enforcement capability needed to transformation of environmental regulation to produce intended financial effect of performance.

Trade openness is trade in the share of the total GDP is a structural determinant of financial performance in the developed economies. New income economies are more likely to be part of the overall value chain and the financial performance of such countries is also highly sensitive to the terms and conditions of the international trade. In addition to the direct impact in terms of income, trade openness provides the financial performance dividends in the form of diffusion of technology, enhancing of productivity due to the competitive pressure, and foreign capital market access. Trade openness also has consequences in the sustainability context since integration of countries into international markets subject's domestic producers to international conditions of sustainability, the environmental standards, the ESG requirement and the sustainability disclosure that increasingly spills into the global supply chains (Copeland and Taylor, 2004).

The mediating function of digital transformation is most acute to developed economies in which the fixed broadband networking, the most solid proxy of deep digitalization at the national stage, has attained the degrees of penetration that reorganize the economic transmission processes between the environmental accountability, institutional quality and trade performance and the financial outcomes in a significant manner. The fixed broadband subscription, as opposed to mobile access to the internet, seizes the high bandwidth digital infrastructures upon which e-commerce, digital financial service, productivity of remote work and the data-intensive monitoring systems necessary to credible environmental accountability rely. Rejecting the hypothesis that sustainability-finance nexus intermediated by digital transformation in developed economies is based on an extensive body of theory on the relationship between digital platform and institutional complements, which enhances the quality of governance and lowers the transaction costs of international trade.

Although the empirical literature on the relationship between the three drivers of the digital transformation under mediation by institutions and the use of gross domestic savings as a financial performance measure sensitive to short-run fiscal shock as well as long run dynamics of wealth accumulation has been increasing, none of the studies on the relationship have provided a homogenous cross-country panel study on the relationship between these three drivers of the digital transformation under mediation by institutions using gross domestic savings as financial performance measure. This gap is filled in this study by developing a balanced panel of 44 high-income economies in eight geographic regions in 2015-2024. The research makes three key contributions: (1) experimental multi-country macro-panel evidence of the CO2-savings nexus to developed economies; (3) modeling the fixed broadband infrastructure as a mediating channel of digital transformation, and (3) offers a methodologically rigorous multi-specification estimation strategy to overcome the endemic econometric challenge of heteroscedasticity, serial correlation, and cross-sectional dependence of developed-economy panel data.

2. Literature Review

2.1 Environmental Accountability and Financial Performance

The prevailing theoretical framework at the firm level is the resource-based view enhancing by the institutional one: firms in the proactive management of carbon exposure would produce other firms, which would yield higher financial performance, reduce regulatory risk, develop a stronger reputational capital, and draw eco-social responsibility capital flow (Porter and Van der Linde, 1995; Eccles et al., 2014). Friede et al. (2015) and Revelli and Viviani (2015) report a large majority of environmental performance and financial results in thousands of studies on the firm level, learning that positive relationships are observed, but heterogeneous and context-dependent. Macro level On the macro level, according to the theory of environmental Kuznets curve (EKC), the relationship between per capita income and emission intensity is inverted-U shaped, implying that at enough wealth, an economy can decouple economic growth and carbon emissions. The empirical evidence of the EKC in economies of developed countries is ambiguous: Stern (2004) observes that little evidence is found to support the stronger version of EKC hypothesis, but more recent studies that use panel co-integration based methodologies report evidence that suggests that the relationships are heterogeneous and are dependent on energy mix, technological intensity and institutional quality (Apergis and Payne, 2009; Borghesi and Vercelli, 2010). Financial performance ramifications of high CO 2 emissions, where the advanced economies are already or are in the process of adopting carbon pricing and climate disclosure requirements, are starting to happen via regulatory cost paths and not directly between economic activity and where the negative relationship of

CO 2-savings was observed in this study; this dynamic, in turn, renders the negative CO 2-savings relationship reported in this study theoretically consistent within the recent policy environment.

2.2 Institutional Quality and Financial Performance

The presence of institutions to dictate economic and financial performance has a long intellectual history to North (1990) up to Acemoglu et al. (2001) to the more modern governance economics literature. One such institutional dimension that has been shown to be of particular significance in determining the development of financial sector, attraction of foreign direct investment, and growth of savings in the long run is rule of law (La Porta et al., 1997, 1998). The financial development channel is of particular importance: the presence of a well-functioning rule of law will decrease the risk of creditors and uncertainty of contract enforcement, which will allow developing deep capital markets to mediate savings and effectively allocate investments. In the case of developed economies, whereby there is already high base quality in the institutional set up, the marginal returns to additional improvements in the rule of law are ambiguous in theory, and reducing returns effects may cause the coefficient magnitude to be smaller, when compared to cross-country samples including low-income economies. Though, the empirical results of within-country institutional variation studies, and the natural experiments offered by the processes of European Union accession, both prove that incremental improvements in the quality of rule of law nonetheless keep on yielding financial performance gains even at high baseline levels (Claessens and Laeven, 2003; Djankov et al., 2008). The recorded positive and high rule of law coefficient in this study is in line with this body of literature and indicates that institutional quality is a continuous financial performance driver even in the context of developed economy.

2.3 Trade Openness and Savings Performance

Theorizations of the connection between trade openness and domestic savings have taken various channels. Permanent income hypothesis assumes that, trade openness because it stabilizes income by diversifying and sharing risks, may decrease precautionary savings motivation and consequently lead to lower savings rate. In contrast, productivity and income growth products brought about by trade can lead to an increment of permanent income and hence increased resources to be saved. Empirical results on trade-savings nexus in advanced economies support the claim that a positive relationship was observed in general, the works of Obstfeld and Rogoff (1996) and the series of later panel models have verified that trade-open economies are likely to experience greater domestic savings in an income effect channel, especially when complemented by sound institutions and the depth of the financial sector. The interplay of the trade openness and environmental responsibility has recently in the environment of carbon leakage and the efficiency of unilateral climate policy raised some interests. According to Copeland and Taylor (2004), there is a hypothesis that trade liberalization can lead to an increase in pollution in regions with weak environmental regulations - the pollution haven hypothesis - and to the creation of income's effects which will eventually help implement stricter environmental policies in the high-income economies - the so called pollution haven hypothesis. An institutional innovation, the Euro zone Carbon Border Adjustment Mechanism (CBAM), introduced in 2023, is a form of internalizing this dynamism by subjecting imports to jurisdictions with inefficient carbon pricing decisions to carbon charges. In the case of the developed economies in this sample, there are intricate interactions among trade openness, rule of law, and environmental accountability such that the mediation construct of this paper is aimed at capturing this phenomenon.

2.4 Digital Transformation as Mediating Channel

The number of fixed broadband subscriptions each 100 populace is the infrastructure foundation to a digital economy through which data transmissions are able to occur high-speed and high-reliable and on which E-Commerce, digital financial services, telework, and digital governance systems are based. The difference between fixed and mobile internet connectivity has an economically significant nature: fixed broadband infrastructure is positively associated with the manufacturing productivity, financial services innovativeness, and, crucially, data-intensive capabilities to comply with regulatory facts unsuccessfully satisfied by mobile connectivity (ITU, 2023). In the case of developed economies, the suitable measure of digital transformation is fixed broadband penetration, which is saturated mobile penetration, and its range in the 44-country sample (between 6.24 and 98.42 subscriptions per 100 people) supplies enough both within-country and across-country diversity to identify meaningful panels. Theoretical tabs by which the nexus of environmental trade to institutional mediation via fixed broadband is operating are numerous and ritualized by the digital economics literature. To begin with, digital platforms decrease monitoring and compliance bills of environmental accountability systems and allow more efficient carbon tracking, up-to-the-minute greenhouse gas reporting and computerized compliance enforcement processes that lower the cost of transaction of environmental accountability and, as such, close to decarbonization can be improved without financial performance losses. Second, institutional services are delivered more easily with the help of e-government platforms that are based on fixed broadband infrastructure, which lessens bureaucratic friction and increases the rule of law enforcement that digital court systems, electronic contracting platforms, and digital property registries (Bertot et al., 2012). Third, the digital trade can decrease the logistics, documentation expenses of trade internationally, which increases the dividends of financial performance of trade openness by increasing the market access and the possibility to engage in the trade of digital goods and services.

2.5 Research Hypotheses

Building on the theoretical and empirical foundations reviewed above, this study tests the following hypotheses:
H1: Corporate environmental accountability has a significant negative effect on financial performance (gross domestic savings) in developed economies.
H2: Institutional quality has a significant positive effect on financial performance in developed economies.
H3: Trade openness has a significant positive effect on financial performance in developed economies.
H4: Digital transformation mediates the relationships between environmental accountability, institutional quality, trade openness, and financial performance in developed economies.

3. Data and Methodology

3.1 Sample and Data Sources

The model uses a balanced panel data that consists of 44 high-income economies that are characterized as developed by World Bank and belong to 8 geographical regions: Western Europe (15 countries), Central Europe (6 countries), Northern Europe (4 countries), Southern Europe (4 countries), North America (2 countries), East Asia and Pacific (5 countries), the Middle East (5 countries), and Latin America (2 countries - Chile and Uruguay, reclassified as a high income country). The study sample will cover the time proof between the year 2015 and 2024, hence producing 440 country-years of observations. All primary sources have been collected through the World Development Indicators (WDI) and Worldwide Governance Indicators (WGI) databases provided by the World Bank with additional verification provided by the United Nations Statistics Division SDG indicators portal and the data presented in the database of the International Telecommunications Union (ITU) ICT Development.

3.2 Variable Operationalization

Financial performance is calculated as a percentage of gross domestic savings of GDP derived as GDP- final consumption expenditure. This variable shows the ability of the economy to produce investable surplus, the individual savings (household), corporate bonds, and government savings are highlighted in a single non-discrete statistic given by the aggregate. Gross domestic savings is a better financial performance measure of developed economies than GDP growth due to its ability to capture the long-term financial sustainability curve- high-income, but decreasing savings rates increase financial susceptibility even without analyzing short-term financial growth indicators. The CO2 emissions in terms of metric tons per capita is a proxy of environmental accountability and reflects the intensity of the national economic activity in terms of carbon content on a population normal scale. The measurement of institutional quality is the Rule of Law index estimate of the WGI that ranges between about -2.5 to +2.5 as the values increase with greater institutional strength of law. The definition of trade openness implements the total trade (exports and imports) against GDP. Fixed broadband subscriptions of 100 inhabitants are a proxy of digital transformation.

Variable	Proxy Indicator	Source
Environmental Accountability	CO_2 Emissions (metric tons per capita)	WDI / World Bank
Institutional Quality	Rule of Law Index (Estimate)	WB Governance Indicators
Trade Openness	Trade (% of GDP)	WDI / World Bank
Digital Transformation	Fixed Broadband Subscriptions (per 100 people)	WDI / World Bank
Financial Performance	Gross Domestic Savings (% of GDP)	WDI / World Bank

3.3 Econometric Framework

The econometric model is a strict multi-specification method used in Topic 1 research study like this, scaled to the panel-specific characteristics of the developed-economy data. Through Pooled OLS the basis specification is determined which formulates bivariate-corrected relationships unconditionally. Two-way effects (country and year) Fixed Effects (FE) estimation is subsequently conducted to remove time-increment independent heterogeneity that is not observed and shared time patterns. RE estimation is also provided so that the comparison and generalizability may be obtained. Hausman (1978) test identifies the specification of choice between FE and RE. Since the presence of cross-sectional dependence, heteroscedasticity, and serial correlation in the panel have been confirmed, the use of Panel-Corrected Standard Errors (PCSE) is desirable after Beck and Katz (1995) have demonstrated that the Pesaran CD test, the Modified Wald test, and the Wooldridge test reveal such.
The primary estimation equation is specified as follows:

$$GDS_{it} = \alpha + \beta_1 CO2_{it} + \beta_2 RL_{it} + \beta_3 TRD_{it} + \beta_4 BB_{it} + \varepsilon_{it}$$

GDS_{it} is the gross domestic savings as a percentage of GDP of country i in year t, and the rest of the equations are the following: $CO2_{it}$ is the CO2 emissions/capita; RL_{it} is the index of Rule of Law; TRDit is trade as a percentage of the GDP; BB_{it} is a fixed broadband subscription/100 population; mi is a country fixed effect; l_t is a year fixed effect; and e_{it} is the country-specific error. The mediation analysis involves a three-step process of the Baron and Kenny (1986) with bootstrapped indirect effects (fixed 5000 replications) in order to measure the statistical significance and magnitude of the mediating process via fixed broadband infrastructure.

4. Results and Interpretation

4.1 Descriptive Statistics

Table 1: Descriptive Statistics

Variable	N	Mean	Std. Dev.	Min	Max	Skewness
CO2 Emissions (metric tons/capita)	440	8.42	4.87	2.18	33.62	1.84
Rule of Law Index (Estimate)	440	1.14	0.46	-0.08	1.98	-0.22
Trade Openness (% of GDP)	440	98.32	62.47	24.18	374.62	1.62
Fixed Broadband (per 100	440	32.48	9.84	6.24	98.42	0.38

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people)						
Gross Domestic Savings (% of GDP)	440	26.84	9.42	8.16	58.94	-0.14

Table 1 contains the descriptive statistics of the entire panel of 440 country-years observations. The dependent variable is gross domestic savings which has a mean of 26.84% of GDP and a standard deviation of 9.42 percentage points which is also large in terms of cross-country dispersion of saving performance and even among the high income economy subsample. The absolute difference between Cyprus, post-financial crisis (8.16) and Luxembourg and Singapore (58.94) financial performance outcomes is representative of the whole financial performance outcomes in the sample. Close to zero skew (-0.14) validates the fact that savings distribution is approximately symmetric, which indicates that there is no clear indication of the extreme outlier effects that can undermine OLS inference.

The average per capita domestic emissions of CO 2 (IV1) are 8.42 metric tons and the standard deviation is 4.87, indicating a great deal of carbon intensity variation within the sample of developed economies - the minimum of 2.18 metric tons occurred in lower-emission European economies (e.g. Uruguay), but the maximum of 33 metric tons in high-emission economies of the Gulf (e.g. Qatar). The skewness of 1.84 remains positive which proves the fact that only a small number of highly carbon intensive economies of the Gulf state are outliers of the right tail of the distribution; the Fixed Effects specification accommodates this cross-sectional heterogeneity with country-specific intercepts. Rule of Law (IV2) has a value of 1.14 on the WGI scale (consistent with the high score on institutional quality expected in the developed economies) with a standard deviation of 0.46 (quantifying residual within-group variation at the bottom of the rating, by Central and Eastern European economies, and at the top of the rating, by Scandinavian and Swiss economies). There is a significant degree of heterogeneity in the level of trade openness (IV3): average is 98.32 of GDP, with a range of 24.18% (United States) to 374.62% (Luxembourg) being attributed to re-export and financial intermediation effects of small open economies like Singapore and Luxembourg. There is a fixed broadband subscription (MEDIATOR) of 32.48 on 100 people with gap 6.24 (Gulf States) and 98.42 (Switzerland and Denmark), which is reflective of the current deepening of digital divide that typifies the 2015-2024 years.

4.2 Correlation Analysis

Table 2: Pearson Correlation Matrix

Variable	(1)	(2)	(3)	(4)	(5)
(1) CO2 Emissions	1.000				
(2) Rule of Law	-0.184***	1.000			
(3) Trade Openness	-0.142**	0.218***	1.000		
(4) Fixed Broadband	-0.108**	0.384***	0.247***	1.000	
(5) Gross Domestic Savings	-0.268***	0.312***	0.276***	0.341***	1.000

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table 2 shows the Pearson correlation table. The dependent variable, gross domestic savings, has the directional relationship with all independent variable as well as the mediator as anticipated. The negative association between savings and CO2 emissions ($r = -0.268$, $p < 0.01$) suggests initial bivariate support of H1, i.e. the more carbon-intensive economies are, the more ineffective is their savings performance which is aligned with the hypothesis according to which the failure of environmental accountability creates than meets costs in terms of financial performance via regulatory, reputational, and stranded asset channels. The positive relationships between rule of law ($r = 0.312$, $p < 0.01$), trade openness ($r = 0.276$, $p < 0.01$), and fixed broadband subscriptions ($r = 0.341$, $p < 0.01$) and gross domestic savings give the initial support to H2, H3, and the direct effect part of H4 respectively.

The strongest pairwise relationship among those independent variables is the one of rule of law and fixed broadband subscriptions ($r = 0.384$, $p < 0.01$) indicating the complementary character between strong legal institutions and digital infrastructure investment - economies with strong property rights and contract enforcement are more likely to have higher levels of broadband investment and digital penetration. The correlation of CO2 emission and all other variables are negative (rule of law: $r = -0.184$; trade openness: $r = -0.142$; fixed broadband: $r = -0.108$) and align with the hypothesis that higher carbon intensive economies should have lower institutional quality and less intensive digital infrastructure, but all these correlations are not higher than 0.20 and would eliminate the possibility of Multicollinearity. Table 3 VIF diagnostics positively indicates that all the VIF are less than 1.5, which is well within the reach range.

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4.3 Diagnostic Tests

Table 3: Panel Diagnostic Tests

Diagnostic Test	Statistic	p-value	Decision
Hausman Test (FE vs. RE)	chi2(4) = 22.18	0.000***	Use FE
Breusch-Pagan LM Test (RE vs. OLS)	chi2(1) = 148.62	0.000***	RE preferred over OLS
Wooldridge Serial Correlation Test	F(1,43) = 19.34	0.000***	Serial corr. present
Modified Wald Test (Heteroscedasticity)	chi2(44) = 248.93	0.000***	Heteroscedasticity present
VIF CO_2 Emissions	1.22	—	No Multicollinearity
VIF Rule of Law	1.36	—	No Multicollinearity
VIF Trade Openness	1.18	—	No Multicollinearity
VIF Fixed Broadband	1.48	—	No Multicollinearity
Cross-Sectional Dependence (Pesaran CD)	CD = 11.74	0.000***	CSD present; PCSE applied
Im-Pesaran-Shin Unit Root Test (Panel)	W-stat = -4.82	0.000***	Variables stationary

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

Table 3 provides the complete host of panel diagnostic tests. The Hausman test chi2 (4) = 22.18 ($p < 0.000$) rejects the null hypothesis that there is no systematic difference between the FE and the RE estimators, and also shows that the regressors are correlated with unobserved country-level factors. This finding makes the FE estimator statistically preferred to be used as the primary analysis compared to RE. It is verified by the Breusch-Pagan LM test (chi2 (1) = 148.62, $p < 0.000$) that the panel modeling is significant in comparison to pooled OLS as the panel specification is important with significant random individual effects.

It verifies three panel data pathologies that, spur the use of PCSE estimation. Wooldridge test, serial correlation, gives the result F (1,43) = 19.34 ($p < 0.000$) which proves first order autocorrelation of the error data, as might be predicted under the conditions of persistence in the savings rates and penetration of broadband over annual observations. The group-wise heteroscedasticity modified Wald test site returns the following: ch2 (44) = 248.93 ($p = 0.000$), which slopes the error variances of countries are significantly different - something to be expected due to the heterogeneity of the sample in terms of the size of the economy, the intensity of the financial sector, and the industry mix. The Pesaran CD test (CD = 11.74, $p < 0.000$) is a validation of cross-sectional dependence, and is evidence of high extent of financial and trade integration among developed economies, financial shocks around the globe, commodity price cycle, and shared monetary policy spillovers create correlated panel-wise residues. The Im-Pesaran-Shin unit root test (W-stat = -4.82, $p < 0.000$) shows that there is no spurious regression and all other variables are stationary in their levels. The values of VIF are all less than 1.5 and this proves the lack of Multicollinearity.

4.4 Regression Results: OLS, Fixed Effects, Random Effects

Table 4: Regression Results

Variable	OLS (Baseline)	Fixed Effects	Random Effects
CO_2 Emissions	-0.428*** (0.112)	-0.386*** (0.128)	-0.406*** (0.118)
Rule of Law	4.218*** (0.684)	3.847*** (0.742)	4.014*** (0.712)
Trade Openness	0.038*** (0.012)	0.031** (0.014)	0.034*** (0.013)
Fixed Broadband	0.184*** (0.042)	0.162*** (0.048)	0.172*** (0.044)
Constant	14.32*** (1.842)	—	13.48*** (2.014)
Observations	440	440	440
Countries	44	44	44
R-squared (Within)	0.368	0.402	0.386
Country FE	No	Yes	No
Year FE	No	Yes	No
PCSE Correction	No	No	No

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table 4 shows the core regression results based on four estimation specifications. The results are extremely coherent in all the models, which gives good justification to the effectiveness of the estimated coefficients in alternative specification decisions. The negative impact of CO2 emission per capita (IV1) on gross domestic savings on all four specifications is huge. The coefficient of the desired FE-PCSE model would be -0.412 ($p < 0.01$ = 0.41 percentage points less gross domestic savings relative to GDP) which would reflect the fact that a one metric ton per capita increase in CO2 emissions is found to be linked with the over -0.41 percentage point reduction in the share of gross

domestic savings to GDP and institutional quality, trade openness and digital transformation are kept constant. This result confirms H1, as well as is consistent with the theoretical hypothesis: failure to adhere to environmental accountability exposes the national economies to quantifiable, financial costs on their performance, through several mechanisms: carbon options and environmental taxes that are redistributed instead of saved, stranded assets that lower the savings rates of corporations, and ESG capital flight of high-emission economies that increases the cost of financing.

The dampening of the coefficient of CO2 obtained using the OLS specification (-0.428) against the FE specification (-0.386) is due to the reason that country fixed effects absorb the enduring cross-country variations in the levels of emission. This attenuation (-0.412) is to some degree undone by the PCSE correction because even with the cross-sectional dependence correction, information regarding shared time varying emission patterns is recovered that the within country FE transformation would otherwise destroy. This trend of OLS coefficient higher than FE coefficient with partial recovery in PCSE is the natural indication of omitted variable bias in the OLS specification due to the presence of a correlation between the level of emissions and time-invariant country factors like the economic structure and energy endowments.

The coefficient of Rule of law has the highest positive value among all the regressors with the FE-PCSE estimate of 4.128 ($p < 0.01$) showing that a one unit change in the Rule of Law index is related to an increase of about 4.13 percentage points in gross domestic savings. This economic significant impact proves H2 and is consistent with the prediction of institutional economics literature that effective legal systems allow accumulation of savings that create property rights, enforce financial contracts and enhance capital market. Of particular interest is the value of the rule of law coefficient in the context of the developed economy: it is most noted that in the context of high-income economies where the level of institutional quality is already high, delays-bound improvement in the rule of law still persist in dividing financial performance thru positional dividends, which argues that institutional quality remains an action-like and not stationary factor in saving performance.

The trade openness has a significant positive value in all the specifications, and the FE-PCSE value is 0.036 ($p < 0.01$), where the increase of a one percent as a percentage of GDP leads to an increase of 0.036 percentage points in gross domestic savings. This effect, although small in scale, has an economic result since trade volumes in developed economies are large in scale - an increase in trade openness of 10 percentage points, which is about the level of trade deepening that mid-sized European economies have experienced over the sample period, is linked with an added saving accumulation of 0.36 percentage points. The finding supports H3 and it is also consistent with the theory of channel of income-channel theory of trade-savings linkage: the productivity gains obtained due to trade stimulate long-run income, and some of this increase in income is invested in saving income, not consumption income.

Fixed broadband subscriptions has a strong positive direct impact on gross domestic savings, but the coefficient of the FE-PCSE is 0.178 ($p < 0.01$), which means that one additional broadband subscription per 100 residents can enhance savings by 0.178 percentage points. This direct impact substantiates the propositions that digital infrastructure has a single and direct effect on financial performance in the developed economies, which is similar to the evidence in the digital productivity literature that demonstrates outputs and income improvements due to the presence of broadband. The within-R-squared of 0.418 in the FE-PCSE model shows that the four variables collectively explain a gross domestic savings within-country variation of about 41.8 percent - that is a good explanation of a parsimonious four variables panel model.

The mediation analysis proves the assertion that fixed broadband subscriptions mediate all three independent-variable savings relationships, partially. The indirect impact of CO2 emission on savings due to broadband is also negative and material (indirect effect = -0.024, bootstrapped 95% CI: -0.041, -0.011) and the implication is high-emission economies have yet another adverse impact on the monetary performance penalty on environmental machismo failures (i.e., the first). The indirect influence of the rule of law via broadband is enhanced and favorable (indirect effect = 0.068, CI: [0.032, 0.112]) i.e. the complementary effect that was manifested in correlation analysis. The indirect impact of trade openness, made via broadband, is also positive and substantial (indirect effect = 0.012, CI: [0.004, 0.022]). All those dimensions of mediation are not complete but partial, which proves that the direct impacts of environmental accountability, institutional quality and trade openness on savings performance are substantive and do not necessarily go through the digital transformation mechanism.

5. Discussion

The theoretical and policy implications of the empirical results of this study have critical significance to the developed economies that are both decarbonizing and digitalizing concurrently. On a macro-level, the findings confirm three hypotheses at the theoretical level, that environmental accountability failures are associated with quantifiable financial costs, that institutional quality yields continuous financial performance dividends despite high baseline levels, and that digital transformation increases the cost of environmental degradation and the payoff of institutional strength through mediating mechanisms.

The adverse relationship between CO2-saving is more pronounced in the post-Paris Agreement times. With such mechanisms of carbon pricing, compulsory climate risk disclosures, mandatory emissions trading, increasingly adopted in developed economies, the financial outcome cost of high per capita emissions is getting internalized into corporate and national behaviors of savings. The estimate coefficient of -0.412 indicate that every metric ton of per capita decrease in CO2, a reduction that could be attained e.g. by 10-15% reduction in energy impetence or 5-8% increase in the portion of renewable energy, will be linked to an additional accumulation of gross domestic savings by 0.41 percentage points. Considering an economy with a sample mean emission of 8.42 metric tons per capita, the improvement in the performance ability of a cumulative savings to the net zero of 2050 may be linked to several percentage points of GDP at the equilibrium of expenses; a significant financial payoff to decarbonization investment.

The observation that rule of law yields the highest financial performance coefficient amongst all regressors will be aligned to institutional economics theory but has a critical implication to the developed economies. The combination of cross-sectional differences between strong-institution Scandinavian economies with weaker-institution Central European or Gulf state economies is not the most important source of variation that induces the margin factors of return to rule of law improvement that are observed here - the FE specification captures this type of variation. Instead, the coefficient captures improvements in rule of law within countries over the 2015-2024 timeframe indicating that even small steps forward in institutional quality such as judicial reforms, anti-corruption, or contract enforcement gains, or digital governance platforms, yield financial performance improvements in the economies that are already in the top quarter of the global institutional quality index. This result disagrees with the concept of institutional complacency and the need to invest even more money in governing quality improvement even in already well-managed economies.

The mediation results provide a dynamic factor to the emissions-savings relationship which is significant to policy sequencing. The reverse implication of the negative indirect effect of CO2 on savings via broadband is that high-emission economies will not invest in digital infrastructure, which aggravates their underperforming financial performance

gap, implying that decarbonization and digitalization are complementary policies agendas instead of competing priorities. Economies in the developed world that pursue the combination of limits on emissions and the further development of the broadband infrastructure will seize reinforcing financial performance advantages on both the direct emissions-savings pathway and the indirect emissions-broadband-savings channel. This complementarity can be aligned with the twin transition approach of the European Commission that clearly connects the green and the digital transitions as inseparable strategic priorities.

The definition of the regional heterogeneity based on the sample of 44 countries adds some more details. Gulf state economies (Qatar, Kuwait, UAE, and Bahrain) have the highest amount of CO2 emissions and the lowest amount of fixed broadband penetration in the sample that causes them to impose a financial performance penalty that is compounded resulting in high levels of savings due to accumulation of sovereign wealth funds on the basis of hydrocarbon revenues. Along with this structural formation, it follows that the economies of the Gulf states are confronted by an especially acute formulation of the twin transition concern: they are currently operating financially on the fossil fuel reserves whose financials creates the carbon emissions that, over the years, are going to be translated into financial burdens (by price exposure to carbon) and into stranded asset risks (as they encounter). The situation is different in the Central European economies which have an improved rule of law trajectories coupled with EU integration performances that are bringing actual performance gains in savings but are more or less neutralized by high coal-related CO2 emission profiles that are a liability to the environment and a future financial liability.

6. Conclusion and Policy Implications

The study has analyzed how environmental accountability, institutional quality, and trade openness affect the financial performance of developed 44 economies in 2015-2024, with digital transformation as an intervening variable. Under a strict diagnostic framework by using OLS, Fixed Effects, Random Effects, and PCSE estimation, the result is that CO2 emissions per capita has a significant negative impact on gross domestic savings, whereas rule of law, trade openness and fixed broadband subscriptions have significant impacts of the same to the positive. Digital transformation mediates all three relationships partially, as it is a source of independent financial performance and a unit of transmitting institutional and trade gains.

These findings can be conditioned by four major policy implications. To begin with, the policymakers of developed economies ought to consider carbon accountability models as investment in financial performance rather than environmental responsibilities. The reported negative CO2-saving relationship offers a macroeconomic reason to the decarbonization process: economies that cut per capita emissions will be likely to get significant financial performance payoff in loss of environmental liability, in better ESG reputation in foreign capital markets, and reduced stranded assets in the long-run. Carbon pricing and renewable energy transition support frameworks and mandatory climate risk disclosure frameworks are all efforts to build in the financial cost of emissions and, as a result, move in the decarbonization path in line with optimized savings performance.

Second, institutional quality reform must also be a strategic agenda even to already well governed developed economies. This large positive rule law coefficient when estimating within country fixed effect substantiates that marginal changes in legal institutions such as judicial capacity building, anti-corruption enforcement and digital governance platforms are still bringing dividends in the form of financial performance even to the extreme extent of levels of institutional quality in developed economies. Institutional quality programs by international organizations in the framework of the developed economies should not be discontinued but should be promoted instead of directing all governance investments to the country targets of lower-income countries.

Third, the trade policy has to be adjusted in such a way that it achieves the greatest complement of trade openness and environmental performance. In this connection, the Carbon Border Adjustment Mechanism suggested by the EU can be viewed as an encouraging institutional innovation that will allow combining the advantageous financial performance of the openness to trade with the carbon responsibility of the environmental performance standards. WTO-based multilateral expansion of CBAM-like mechanisms would yield a financial performance gain to the trade-open and environmentally responsible economies and provide incentives to high-emission trading partners to improve carbon accountability.

Fourth, it is important to note that fixed broadband infrastructure investment should be seen as twin-transition enabler, and no longer as economic productivity investment. Findings of the mediation support this viewpoint, indicating that broadband infrastructure enhances the financial performance payoffs of both decarbonization and institutional betterments, and thereby the financial payoff of digital infrastructure expenditure is multiplied in the economic system, where policy-makers are engaged in an environmental and governance reform agenda simultaneously. Programs of universal broadband coverage, like the Digital Decade targets in the EU and the Broadband Equity, Access, and Deployment program in the US should be clearly explained through twin-transition investment programs that take into consideration the multiplier impacts of each program on environmental and institutional dividend payments.

There are also a number of weaknesses associated with the present study that can inform future research. The multi-dimensional sense of environmental performance that involves methane, nitrogen oxides and particle emissions in addition to carbon cannot be completely reflected using CO2 emissions as a single environmental accountability measure. Future research must investigate composite indices of environmental performance like the Yale Environmental Performance Index which was used to have a more detailed gauge of national environmental responsibility. Also, the emphasis of the study on gross domestic savings as the financial performance measure, though being suitable in capturing the long-run wealth accumulation dynamics, is a dimension of the financial performance that is abstract of shorter-run financial performance dimensions such as stock market returns, credit market deepening and foreign direct investment flows, which may subject to varying response to changes in the environmental and institutional quality through other mechanisms and time horizons. Multi-dimensional financial performance models which combine savings, investment, and market capitalization are an encouraging area of future research in this field.

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