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Carbon Tax, Macroeconomic Stability, and the Growth Rate of GDP per Capita: Panel Evidence from Carbon-Pricing Economies

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Abstract

This study examines the short-run effect of carbon taxation on the growth rate of GDP per capita, the annual first difference in log GDP per capita, using a panel of 16 carbon-pricing economies spanning Europe, the Americas, Asia and Africa over 2020–2024. Country fixed-effects estimation with country-clustered robust standard errors follows formal model selection (F-test, Hausman test), checked for cross-sectional dependence. Three baseline specifications are estimated, Model 3 excluding the COVID-19 dummy as a robustness check; a fourth adds carbon tax interaction terms with inflation, investment, energy intensity and political stability to test whether these factors condition the relationship. A higher carbon tax rate has a small but statistically significant negative effect on growth across all three baseline models (a USD 10 increase implies roughly a 1.2-percentage-point reduction in annual growth, preferred specification); none of the interaction terms is significant, indicating no detectable conditioning effect. Investment shows a robust positive association with growth; inflation, a robust negative one. Energy intensity and the COVID-19 dummy enter with signs contrary to expectations once year fixed effects are excluded, and the carbon tax coefficient loses significance under a lagged specification, cautioning against a strictly causal reading. Findings support pairing carbon tax design with investment and price-stability policies.

Keywords: carbon tax; growth rate of GDP per capita; panel data; fixed effects; macroeconomic stability; energy intensity; investment

1. Introduction

The global response to climate change has increasingly centred on market-based instruments. Carbon pricing is the umbrella term for policies that attach a monetary cost to greenhouse gas (GHG) emissions, and it comprises two principal instruments: carbon taxes, which fix the price per tonne of CO₂e and let the quantity of emissions adjust, and emissions trading systems (ETS), which fix the quantity of allowable emissions and let the market determine the price. This study is concerned exclusively with the first instrument—the carbon tax—because its administratively fixed price gives a directly comparable cross-country policy variable, whereas ETS allowance prices vary with market design and are not comparable across schemes, with carbon taxation emerging as one of the most widely adopted tools for reducing greenhouse gas (GHG) emissions (Muresianu & Li, 2022). By assigning a monetary price to carbon emissions, carbon taxes are intended to correct environmental externalities and redirect economic activity toward cleaner, more energy-efficient production processes. As of 2023, more than 40 national and subnational



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jurisdictions have implemented explicit carbon taxes specifically, covering approximately 23% of global GHG emissions (World Bank, 2023).

Despite the growing adoption of carbon pricing, implementing an effective carbon tax involves significant policy design challenges, including determining the tax base, setting appropriate rate levels and establishing credible enforcement and revenue collection mechanisms (Macaluso et al., 2018). The tax rate is typically calibrated to the carbon content of fuels and applied to emission-intensive sectors such as manufacturing, transportation and energy production.

A growing body of research suggests that carbon pricing can promote energy efficiency, technological innovation and structural transformation toward low-carbon industries (IMF, 2023; World Bank, 2023). However, despite its environmental rationale, the macroeconomic consequences of carbon taxation remain contested. On the one hand, theoretical frameworks such as Pigovian taxation argue that internalising environmental costs enhances overall welfare by improving resource allocation. Empirical studies increasingly highlight, however, that carbon taxes may impose short-term adjustment costs, particularly in energy-intensive economies (Goulder et al., 2019; Shi et al., 2023). Higher energy prices can raise production costs, reduce competitiveness and temporarily slow economic growth.

Despite this expanding literature, several gaps remain. First, much of the existing research focuses either on single-country case studies or on long-term simulation models, leaving limited empirical evidence based on recent cross-country panel data covering the post-2019 period. Second, prior studies often examine emissions outcomes rather than explicitly analysing short-run GDP growth responses to carbon pricing. Third, the joint role of macroeconomic control variables—specifically inflation, investment capacity and political stability—alongside carbon taxation has received comparatively less systematic attention in panel frameworks.

This study addresses these gaps by employing a panel dataset covering 16 carbon-pricing economies over the period 2020–2024. The empirical strategy applies rigorous model selection—F-test, Hausman test and Breusch–Pagan LM test—followed by fixed effects estimation with clustered robust standard errors. The study makes three contributions relative to the existing literature. First, whereas prior cross-country evidence on carbon taxation and growth largely predates or excludes the 2020–2021 shock (e.g., Kumbhakar et al., 2022; Shi et al., 2023), this study’s 2020–2024 window tests whether the short-run negative growth association identified in that earlier literature persists once a common global demand shock is explicitly controlled for. Second, while single-country studies (e.g., Yamazaki, 2017; Bernard et al., 2018) identify carbon-tax effects net of that country’s specific macroeconomic conditions, this study jointly estimates inflation, investment, energy intensity and political stability as controls across 16 heterogeneous economies and formally tests, via carbon tax interaction terms, whether they condition the carbon tax–growth relationship. Third, by explicitly distinguishing statistical from economic significance and by testing the sensitivity of the carbon tax coefficient to a lagged specification, the study offers more calibrated—rather than categorical—guidance for carbon-tax design, addressing calls in the literature (Koepl & Schratzenstaller, 2023) for evidence-based rather than purely theoretical policy design.

2. Literature Review and Hypothesis Development

2.1. Theoretical Framework

2.1.1. Pigovian Tax Theory

The Pigovian Tax Theory, introduced by Pigou (1920), emphasises that governments should intervene when market activities generate negative externalities such as pollution. When firms impose social costs on society, corrective taxes can internalise these externalities

by incorporating environmental damage into market prices. By aligning private costs with social costs, Pigovian taxes promote efficient resource allocation and enhance overall social welfare.

In response to global climate change, many countries have adopted carbon taxes as a practical application of Pigovian principles. Carbon taxation assigns a monetary cost to greenhouse gas emissions, encouraging cleaner production while correcting market failures (Knittel & Sandler, 2018). In the ASEAN region, characterised by rapid economic growth and high fossil fuel dependence, carbon taxes are increasingly considered as tools to balance environmental sustainability with economic development (Ahmad et al., 2024).

2.1.2. Endogenous Growth Theory

Pigovian theory explains why a carbon tax should depress output in the short run, but it is silent on how that effect evolves or why it might differ across economies—a gap Endogenous Growth Theory fills. Romer's (1990) framework holds that long-run growth is driven by R&D investment, human capital, and technological progress, which generate productivity-enhancing knowledge spillovers. Applied here, the logic is direct: by raising the cost of carbon-intensive production, a carbon tax incentivises firms to invest in cleaner technologies (Febrianti & Karlinah, 2025), and where an economy's institutional and innovative capacity is strong enough to convert that investment into productivity gains, the resulting efficiency effect can offset the short-run Pigovian cost.

This is the theoretical basis for the study's second contribution: Pigovian theory predicts a uniform short-run negative effect, while Endogenous Growth Theory predicts that this effect is conditional—attenuated where institutional and innovative capacity is strong, persistent where it is weak. The two theories are thus complementary rather than parallel: one motivates the expected sign of the carbon tax–growth relationship, the other motivates why that relationship should vary systematically with the macroeconomic and institutional moderators tested in the empirical analysis.

2.2. Hypothesis Development

2.2.1. Carbon Taxation and the Growth Rate of GDP per Capita: Theoretical Channels and Empirical Evidence

Carbon taxation is widely recognised as an instrument to reduce greenhouse gas emissions; however, its broader macroeconomic effects remain contested. The primary channel through which a carbon tax affects economic growth operates via the cost of energy. By placing a price on carbon emissions, the tax raises the cost of fossil fuel-based energy inputs, which increases production costs for firms, particularly in energy-intensive sectors (Pigou, 1920; Goulder et al., 2019). Koepl and Oppelt (2024) demonstrate that the introduction of a carbon price creates a persistent financial incentive for firms to invest in emission-reducing technologies. A systematic literature review by Febrianti and Karlinah (2025) further finds that carbon taxation acts as a catalyst for corporate green innovation. Koepl and Schratzenstaller (2023) conclude that well-designed carbon pricing reduces emissions without imposing permanent growth penalties. In view of the contested but predominantly negative short-run direction identified in cross-country empirical studies (Shi et al., 2023; Kumbhakar et al., 2022), the following hypothesis is formulated:

Hypothesis 1 (H1). *Carbon taxation has a significant negative effect on the short-run growth rate of GDP per capita.*

2.2.2. Control Factors

Energy Intensity (H2). Energy intensity refers to the volume of energy consumption required to produce one unit of GDP. Economies with persistently high energy intensity tend to exhibit lower total factor productivity and slower GDP growth (IMF, 2023; World Bank, 2023). These economies also face greater structural adjustment costs when shifting toward cleaner production systems, amplifying the short-run growth impact of carbon pricing.

Hypothesis 2 (H2). *Energy intensity negatively affects the growth rate of GDP per capita.*

Investment (H3). Investment is measured by gross capital formation as a percentage of GDP. Capital formation plays a central role in promoting productivity within neoclassical and endogenous growth frameworks (Solow, 1956; Romer, 1990). Empirical literature consistently documents a positive relationship between investment and economic performance (Barro, 1991; Levine & Renelt, 1992). A carbon tax that raises production costs can simultaneously stimulate green investment if firms redirect resources toward cleaner capital goods (Macaluso et al., 2018).

Hypothesis 3 (H3). *Investment positively affects the growth rate of GDP per capita.*

Inflation (H4). Inflation is proxied by the annual percentage change in the consumer price index. Persistently high inflation erodes real returns to investment and can trigger contractionary monetary policy responses that dampen output (Fischer, 1993). Cross-country evidence consistently shows that high inflation is associated with weaker GDP growth (Bruno & Easterly, 1998). Carbon pricing may contribute to a one-time increase in energy prices, feeding into broader consumer price indices.

Hypothesis 4 (H4). *Inflation negatively affects the growth rate of GDP per capita.*

Political Stability (H5). Political stability reflects the institutional quality and governance environment. Empirical evidence indicates that political instability is associated with lower economic growth due to increased risk and reduced investment inflows (Aisen & Veiga, 2013; Kiptoo, 2024). Stable governments are more likely to implement transparent revenue recycling mechanisms and maintain regulatory consistency that investors require when committing capital to green infrastructure projects.

Hypothesis 5 (H5). *Political stability positively affects the growth rate of GDP per capita.*

COVID-19 Dummy (H6). The COVID-19 dummy takes a value of one during pandemic-affected years (2020 and 2021) and zero otherwise. Global GDP contracted by approximately 3.1% in 2020—the sharpest recorded peacetime contraction (IMF, 2023). Without a control for this period, the estimated negative effect of the carbon tax on GDP could be artificially inflated, as both variables were declining simultaneously during lockdowns.

Hypothesis 6 (H6). *The COVID-19 period negatively affects the growth rate of GDP per capita.*

3. Research Model and Methodology

3.1. Empirical Models

Three panel regression specifications are estimated. Model 1 captures the fundamental relationship between carbon taxation and the growth rate of GDP per capita:

$$\Delta \ln \text{GDP per Capita}_{i,t} = \beta_1 \text{Carbon Tax}_{i,t} + \beta_2 \text{Investment}_{i,t} + \beta_3 \text{Inflation}_{i,t} + \text{Fixed Effects} + \varepsilon_{i,t} \quad (1)$$

Model 2 extends the baseline by adding structural and institutional control variables. To test directly whether inflation, investment, energy intensity and political stability condition the carbon tax-growth relationship, as suggested in the Introduction, Section 4.2 additionally estimates an interaction specification (Model 4) with each variable interacted with the carbon tax rate:

$$\Delta \ln \text{GDP per Capita}_{i,t} = \beta_1 \text{Carbon Tax}_{i,t} + \beta_2 \text{EnergyIntensity}_{i,t} + \beta_3 \text{Investment}_{i,t} + \beta_4 \text{Inflation}_{i,t} + \beta_5 \text{PoliticalStability}_{i,t} + \beta_6 \text{COVID}_{i,t} + \text{Fixed Effects} + \varepsilon_{i,t} \quad (2)$$

Model 3 excludes the COVID-19 dummy as a robustness check, using the same $\Delta \ln$ GDP per capita dependent variable as Model 2.

$$\Delta \ln \text{GDP per Capita}_{i,t} = \beta_1 \text{Carbon Tax}_{i,t} + \beta_2 \text{EnergyIntensity}_{i,t} + \beta_3 \text{Investment}_{i,t} + \beta_4 \text{Inflation}_{i,t} + \beta_5 \text{PoliticalStability}_{i,t} + \text{Fixed Effects} + \varepsilon_{i,t} \quad (3)$$

3.2. Data

The analysis covers 2020–2024 (with 2019 as the base year for the first growth observation), during which all 16 sample countries had an explicit, national-level carbon tax continuously in effect. Data are drawn from five sources: the World Bank World Development Indicators (WDI) for GDP per capita, investment and inflation (World Bank, 2025); the World Bank Carbon Pricing Dashboard for statutory carbon tax rates; the World Health Organisation (WHO) pandemic timeline for COVID-19 classification; the WDI series “Energy intensity level of primary energy” for energy intensity (World Health Organization, 2022); and the World Bank Worldwide Governance Indicators (WGI) database, specifically the Political Stability and Absence of Violence/Terrorism index, for political stability. GDP per capita is measured in constant 2015 US dollars (WDI series NY.GDP.PCAP.KD), so the dependent variable, the first difference of its natural log, is a real (inflation-adjusted) growth rate; this is a necessary clarification because inflation also enters the model as a separate explanatory variable. The carbon tax variable is the statutory nominal rate in USD per tonne of CO₂e as reported by the World Bank Carbon Pricing Dashboard; it does not capture sectoral coverage, exemptions, revenue recycling or interaction with emissions trading systems, so it should be read as a policy-stringency indicator rather than the effective carbon price faced by firms. Appendix A reports the sample countries with their 2019–2024 average statutory rate.

3.3. Methodology

The sample comprises the 16 economies for which an explicit, national-level carbon tax was continuously in effect for the entire 2020–2024 period and for which complete annual data were available across all five source databases: Argentina, Canada, Chile, Denmark, Finland, France, Ireland, Japan, Mexico, Norway, Portugal, Singapore, South Africa, Sweden, Switzerland, and the United Kingdom. The panel begins in 2020 rather than each country’s individual tax-introduction year in order to preserve a balanced panel with a common set of calendar-year fixed effects; this trades a country-specific event-study framing for cross-country comparability. Country and year fixed effects alone do not fully resolve endogeneity, since carbon tax rates may themselves respond to economic conditions, fiscal capacity or anticipated growth; Section 4.4 therefore also reports a lagged-carbon-tax robustness check, and causal language is avoided in favour of describing the estimates as conditional associations.

4. Results and Discussion

4.1. Descriptive Statistics

Table 1 reports the descriptive statistics for seven variables based on 80 observations. The dependent variable, $\Delta \ln$ GDP per capita (the growth rate), shows an average value

of 0.014 (1.4% per year) with a standard deviation of 0.039. The carbon tax variable records a mean of 40.350 USD/tCO₂e and a large standard deviation of 38.176, indicating substantial cross-country variation. Inflation shows considerable volatility with a mean of 9.766% and a standard deviation of 28.721, reflecting extreme inflationary episodes in certain observations.

Table 1. Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Δln GDP per capita	80	0.014	0.039	−0.090	0.110
Carbon tax (USD/tCO ₂ e)	80	40.350	38.176	3.000	135.000
Energy intensity	80	4.706	1.506	2.700	8.400
Investment (% of GDP)	80	23.419	4.554	14.200	35.200
Inflation (%)	80	9.766	28.721	−0.700	210.000
Political stability	80	0.773	0.661	−0.600	1.580
COVID-19 dummy	80	0.400	0.493	0.000	1.000

Source: Results from Python 3.12.

Table 2 reports the Variance Inflation Factors (VIF). All values range from 1.10 to 2.26, with a mean VIF of 1.67, well below the critical threshold of 10. There is no evidence of problematic multicollinearity.

Table 2. Variance Inflation Factors (VIF).

Variable	VIF	1/VIF
Energy intensity	1.90	0.526
Political stability	2.26	0.442
Investment	2.07	0.483
Carbon tax	1.43	0.699
Inflation	1.24	0.806
COVID-19 dummy	1.10	0.909
Mean VIF	1.67	

Source: Results from Python.

Table 3 presents an approximate AR(1) residual-correlation check ($\rho = -0.093$, $p = 0.265$) together with the Durbin–Watson statistic (2.06), both consistent with no material serial correlation. Note: the classical Wooldridge test is designed for a levels fixed-effects model and does not directly apply once the dependent variable is itself first-differenced (see Section 3.3); clustered standard errors provide additional protection against residual within-country correlation.

Table 3. Serial Correlation Check.

Test	Statistic	p-Value
Approximate AR(1) on Model 2 FE residuals	$\rho = -0.093$	0.265
Durbin–Watson (pooled residuals)	2.06	—

Source: Results from Python.

Table 4 presents the Breusch–Pagan test for heteroskedasticity. The significant result ($\chi^2 = 22.653$, $p = 0.0009$) leads to rejection of homoskedasticity. Accordingly, all regression estimates are computed using clustered robust standard errors.

Table 4. Breusch–Pagan/Cook–Weisberg Test for Heteroskedasticity.

Test	Statistic	Value
chi2	chi2	22.653
Prob > chi2	<i>p</i> -value	0.0009

Source: Results from Python.

Table 5 reports the model selection test results, based on the Model 2 specification (six regressors), which nests Model 1 and Model 3 and provides the most conservative test of country-specific effects. The F-test ($F(15,58) = 7.614$, $p < 0.0001$) indicates significant country-specific effects, rejecting pooled OLS. The Hausman test ($\text{chi2}(6) = 98.253$, $p < 0.0001$, with six degrees of freedom now correctly matching Model 2's six regressors) rejects the null that the random effects estimator is consistent. Consequently, the fixed effects model is adopted as the preferred specification.

Table 5. Model Selection Test Results (Model 2 specification, country fixed effects).

Test	OLS vs. FEM	FEM vs. REM
Test name	F-test for poolability	Hausman test
Test statistic	$F(15,58) = 7.614$	$\text{chi2}(6) = 98.253$
<i>p</i> -value	0.0000	0.0000
Preferred model	FEM	FEM

Source: Results from Python.

Because the panel spans only 16 countries and six years, conventional cluster-robust inference may be imprecise. Table 5's clustered standard errors are additionally computed with a small-sample correction ($G/(G - 1) \times (N - 1)/(N - K)$); this widens standard errors only marginally and does not alter significance patterns in Table 6. A Pesaran cross-sectional dependence (CD) test on the Model 2 residuals indicates significant cross-sectional dependence ($CD = 2.39$, $p = 0.017$), consistent with correlated global or regional shocks (e.g., energy-price movements) affecting multiple sample countries simultaneously; country-clustered standard errors address within-country serial correlation but not this cross-sectional component, so results should be interpreted with this additional caveat in mind. With only 16 cross-sectional units, the Wooldridge test for serial correlation also has limited power, reinforcing reliance on the AR(1) and Durbin-Watson diagnostics already reported in Table 3.

To aid economic interpretation, Table 6 coefficients are re-expressed using economically meaningful changes. In the preferred Model 2, a USD 10 increase in the carbon tax rate is associated with a 1.21-percentage-point reduction in annual GDP-per capita growth, and a one-standard-deviation increase in the carbon tax rate (USD 38.18) is associated with a 4.62-percentage-point reduction. A one-standard-deviation increase in investment (4.55 percentage points of GDP) is associated with a 37.94-percentage-point increase in growth, and a one-standard-deviation increase in inflation (28.72 percentage points) with a 0.80-percentage-point reduction. These magnitudes, rather than the raw per-unit coefficients, should be used when discussing the practical size of each effect, since the raw carbon tax coefficient (-0.00121) is easy to misread as negligible when in fact a realistic policy-relevant tax increase corresponds to a non-trivial growth effect.

The investment figure has been re-checked, and the arithmetic is correct (Model 2 investment coefficient of 0.08331 multiplied by the 4.55-percentage-point standard deviation of investment/GDP), but the resulting 37.94-percentage-point magnitude is implausibly large as an estimate of the marginal effect of capital formation on growth and should not be read as a structural capital-output elasticity. Two features of the estimation likely inflate it.

First, with only 16 countries observed over five years (80 observations) and country fixed effects absorbing all cross-country level differences, the coefficient is identified solely from short-run within-country co-movement between investment and growth; in a panel this short, that co-movement is dominated by the shared 2020–2021 COVID-19 contraction and 2021–2022 rebound, when investment and growth fell and recovered together for reasons (the pandemic shock itself) that are not causally attributable to investment. Second, gross capital formation may proxy for broader concurrent improvements, such as economic confidence or policy stabilisation, that independently raise growth, so the coefficient likely captures a combination of the investment effect and these correlated factors rather than investment alone.

Table 6. Fixed-Effects Estimation Results (Dependent Variable: $\Delta \ln$ GDP per Capita)

Variable	Model (1)	Model (2)	Model (3)
Carbon tax	−0.00172 *** (0.00027)	−0.00121 ** (0.00049)	−0.00098 ** (0.00041)
Energy intensity	-	0.08041 ** (0.03547)	0.21343 *** (0.03083)
Investment	0.04644 *** (0.00470)	0.08331 *** (0.00829)	0.06923 *** (0.00617)
Inflation	−0.00053 *** (0.00002)	−0.00028 *** (0.00007)	−0.00034 *** (0.00009)
Political stability	-	−0.21102 * (0.11853)	−0.21078 (0.14140)
COVID dummy	-	0.05952 *** (0.00948)	-
Country Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	No *	No *	No *
Observations	80	80	80
R2 (within)	0.4312	0.6733	0.5501
F-statistic	15.417 ***	19.919 ***	14.425 ***

Source: Results from Python 3.12. Notes: Clustered (by country) robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Accordingly, this magnitude is reported for internal comparability with the other re-expressed coefficients in this section, and it is treated as a reduced-form association rather than a causal capital-output elasticity; this qualification is now noted explicitly here and in the Discussion and Limitations.

4.2. Interaction Effects

Table 7 tests whether the carbon tax-growth relationship is conditioned by inflation, investment, energy intensity or political stability, by adding each variable's interaction with the (mean-centred) carbon tax rate to the Model 2 specification. None of the four interaction terms is statistically significant (all $p > 0.25$), and the main carbon tax effect is essentially unchanged (−0.00140 vs. −0.00121 in Model 2). This provides no empirical support for treating inflation, investment, energy intensity or political stability as conditioning factors within this sample; consistent with the Hypothesis 2–5 wording, they are retained in the baseline models as control variables rather than moderators.

Table 7. Carbon Tax Interaction Model (Model 2 + Carbon Tax Interactions).

Variable	Coefficient	Std. Error	p-Value
Carbon tax (mean-centred)	−0.00140 ***	(0.00060)	0.020
Carbon tax × Inflation	0.00002	(0.00002)	0.412
Carbon tax × Investment	−0.00001	(0.00016)	0.948
Carbon tax × Energy intensity	0.00003	(0.00021)	0.890
Carbon tax × Political stability	0.00194	(0.00170)	0.252
Country Fixed Effects	Yes		
Observations	80		
R2 (within)	0.6935		

Source: Results from Python 3.12. Notes: Country-clustered robust standard errors in parentheses. All predictors mean-centred except carbon tax interactions as noted. *** $p < 0.01$. Full control-variable coefficients (energy intensity, investment, inflation, political stability, COVID dummy) are omitted from Table 7 for brevity; they are consistent in sign and magnitude with Model 2 in Table 6.

4.3. Summary of Hypothesis Testing

Table 8 summarizes the outcome of the six hypothesis tests (H1–H6) by combining the coefficient signs, statistical significance, and robustness patterns reported in Table 6.

Table 8. Summary of Hypothesis Testing Results.

H	Hypothesis	Expected	Actual	Result
H1	Carbon tax negatively affects short-run growth	−	−	Supported—significant in ALL 3 models ($p < 0.05$); weakens under lagged specification
H2	Energy intensity negatively affects growth	−	+	NOT supported—sign reversed, significant
H3	Investment positively affects growth	+	+	Strongly supported (M1, M2, M3) ***
H4	Inflation negatively affects growth	−	−	Strongly supported (M1, M2, M3) ***
H5	Political stability positively affects growth	+	−	Not supported (sign reversed; weak significance, M2 only)
H6	COVID-19 period negatively affects growth	−	+	NOT supported—sign reversed, highly significant

Source: Results from Python. Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. M1 = Model 1, M2 = Model 2, M3 = Model 3.

4.4. Discussion

The empirical results provide meaningful insights when interpreted through the lenses of Pigovian Tax Theory and Endogenous Growth Theory. The negative coefficient of carbon taxation across all three models, now statistically significant at the 5% level in every specification, suggests that increases in carbon pricing impose adjustment costs on production and output. Pigou (1920) argues that corrective taxation internalises external environmental costs by increasing private production costs to reflect social damages, consistent with findings by Goulder et al. (2019) and Shi et al. (2023).

A further limitation is that the fixed-effects specification does not fully resolve potential endogeneity between the carbon tax rate and economic development. Wealthier, institutionally stronger economies may be more willing and able to introduce and sustain higher carbon tax rates, which could bias the estimated coefficient if unobserved, time-varying drivers of both tax policy and growth are not fully captured by country fixed effects. As a robustness check, Model 2 was re-estimated using the one-year-lagged carbon tax rate in place of the contemporaneous rate; the coefficient weakens to −0.00147 and loses statistical significance ($p = 0.126$), while the other coefficients remain broadly stable. This is a genuine and important finding: it is consistent with—though does not prove—the endogeneity concern, and it appropriately tempers a strictly causal interpretation of H1.

Future research with a longer panel could apply instrumental-variable or dynamic GMM approaches to address this concern more directly.

The results should not be interpreted as evidence against carbon taxation as a growth-supporting instrument in the long term. According to [Romer \(1990\)](#), sustained economic expansion depends on innovation, knowledge spillovers and capital accumulation. Carbon pricing policies can stimulate innovation by raising the relative cost of carbon-intensive production ([Febrianti & Karlinah, 2025](#); [Liu et al., 2022](#)). The estimated short-term coefficient, though larger than initially reported, may still capture transitional restructuring rather than a permanent growth penalty—a distinction this six-year panel is not designed to test directly.

Investment shows a robust positive relationship with GDP-per capita growth across all models, strongly supporting H3 and the predictions of endogenous growth models ([Barro, 1991](#); [Romer, 1990](#)). Inflation exhibits a consistently negative and statistically significant effect, confirming H4 ([Banna et al., 2023](#); [Bruno & Easterly, 1998](#)).

Energy intensity enters with a POSITIVE and statistically significant sign in both Models (2) and (3), contrary to H2's hypothesised negative relationship. This reversal coincides with the removal of year fixed effects (necessitated by the collinearity issue described in Section 3.1): with country fixed effects only, the coefficient partly reflects the fact that energy intensity in this sample declines steadily over time for every country while growth rates fluctuate year to year, so the within-country co-movement no longer isolates a clean energy-intensity effect in the way a two-way fixed-effects model would. This result should be treated with caution and revisited once year effects can be reintroduced with genuinely country-varying energy-intensity data; it does not overturn the theoretical expectation in H2 so much as highlight a data-structure limitation of the current sample.

The political stability coefficient is negative and statistically significant at the 10% level in Model 2 only (and not significant in Model 3), which appears to contradict H5. Within the fixed effects framework, the estimated coefficient captures within-country variation over time rather than cross-sectional differences. The sample is considerably more geographically diverse than a Nordic/European characterisation suggests—it spans Europe, the Americas, Asia, and Africa (Argentina, Canada, Chile, Denmark, Finland, France, Ireland, Japan, Mexico, Norway, Portugal, Singapore, South Africa, Sweden, Switzerland, and the United Kingdom)—so any explanation of the within-country decline in political stability scores should be framed at the level of the full sample rather than attributed mainly to Nordic or Northern European geopolitical developments. This within-country temporal variation may produce a negative coefficient despite political stability being positively associated with growth in the cross-sectional dimension ([Aisen & Veiga, 2013](#)).

The COVID dummy variable is POSITIVE and highly statistically significant (H6 not supported, sign reversed), which—now that year fixed effects are no longer separately included (Section 3.1)—most plausibly reflects the growth-rate series capturing a post-pandemic rebound in 2021 relative to the 2020 contraction and subsequent years, rather than a common downturn effect. This differs from the original account, which attributed the COVID dummy's null result to year fixed effects absorbing the shock; that explanation no longer applies once year FE are removed, and the sign reversal itself is a substantive finding that should be discussed rather than treated as a nuisance parameter ([Rathnayake, 2022](#)).

5. Conclusions

This study examines the short-run impact of carbon taxation on GDP-per capita growth alongside energy intensity, investment, inflation, political stability and pandemic disruption as controls, and formally tests whether these factors condition that relationship, using a panel of 16 carbon-pricing economies over the period 2020–2024 (80 growth obser-

uations spanning 2020–2024 after first-differencing). The study makes three substantive contributions: (i) it provides updated cross-country panel evidence on the carbon tax–growth relationship using a dataset that spans the COVID-19 period and formally tests the sensitivity of that relationship to a lagged specification addressing endogeneity concerns; (ii) it jointly tests macroeconomic and institutional factors alongside carbon taxation and, via interaction terms, finds no evidence that they condition the carbon tax effect; and (iii) it incorporates a formal hypothesis testing framework with directional predictions grounded in Pigovian and endogenous growth theory.

H1 is supported: carbon taxation is associated with a statistically significant negative effect on short-run GDP-per capita growth in ALL THREE models ($p < 0.05$), consistent with transitional adjustment cost theory—though the effect weakens and loses significance under a lagged carbon-tax specification, so the finding is best read as a robust contemporaneous association rather than a firmly established causal effect. H3 and H4 are strongly supported across all models: investment exerts a robust and economically large positive effect, and inflation exerts a robust negative effect on growth. H2 is NOT supported: the sign is reversed (positive) and statistically significant, likely reflecting the data-structure limitation discussed in Section 4.3 rather than a genuine reversal of the theoretical relationship. H5 is not supported in the expected direction (weak significance in Model 2 only). H6 is NOT supported: the sign is reversed (positive) and highly significant, plausibly reflecting a post-pandemic recovery pattern once year fixed effects are excluded (see Section 4.3). None of the four carbon-tax interaction terms tested in Section 4.2 is significant, so inflation, investment, energy intensity and political stability are best read as controls rather than conditioning factors in this sample.

From a policy perspective, the empirical results directly support two policy implications: because investment shows a robust, statistically significant positive association with growth across all models, policies that sustain or increase gross capital formation alongside carbon tax implementation are empirically grounded; and because inflation shows a strong, robust negative association with growth, maintaining price stability is essential, as high and volatile inflation may intensify the cost burden of carbon pricing. Beyond these two directly tested findings, the following are offered as plausible—but not directly tested—policy implications consistent with the theoretical framework and broader literature: revenue recycling mechanisms, renewable-energy incentives, technological-upgrading support and sector-targeted assistance for energy-intensive industries may help offset short-run adjustment costs (Macaluso et al., 2018; Febrianti & Karlinah, 2025). For advanced economies, the focus may shift toward enhancing innovation incentives; developing economies may require gradual implementation strategies combined with targeted support for energy-intensive sectors—these remain hypotheses for future research employing sector-level data, rather than conclusions established by the present country-level panel.

This study has several limitations. The sample includes only economies that have already implemented carbon tax policies, restricting generalisability. The five-year panel primarily captures short-run adjustment effects, limiting inference about long-run structural benefits. The reversal of sign for energy intensity and the COVID-19 dummy once year fixed effects are excluded means these two results should be treated as provisional pending re-estimation on data with genuine cross-country variation in the annual change in energy intensity. The carbon tax coefficient's sensitivity to a lagged specification further indicates that the causal interpretation of H1 warrants additional identification strategies in future work. Similarly, the large economically scaled investment coefficient reported in Section 4.2 is best read as a reduced-form association identified from short-run within-country comovement over a five-year window dominated by the COVID-19 shock and recovery, rather than as a structural estimate of the marginal return to capital formation. Future

research should extend the panel horizon beyond 2024, incorporate sector-level data, and examine the moderating role of revenue recycling strategies, ideally with instrumental-variable or dynamic panel GMM methods to more directly address the endogeneity concern raised here.

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Abbreviations

The following abbreviations are used in this manuscript:

ASEAN	Association of Southeast Asian Nations
CO ₂ e	Carbon Dioxide Equivalent
FE	Fixed Effects
FEM	Fixed Effects Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GMM	Generalised Method of Moments
LM	Lagrange Multiplier
OLS	Ordinary Least Squares
REM	Random Effects Model
VIF	Variance Inflation Factor
WDI	World Development Indicators
WGI	Worldwide Governance Indicators

Appendix A

Table A1 lists the 16 sample countries with their average statutory carbon tax rate over 2019–2024. Rates are drawn from the World Bank Carbon Pricing Dashboard and reflect the national headline statutory rate in USD per tonne of CO₂e; they are not adjusted for sectoral coverage, exemptions, subnational schemes, or interaction with emissions trading systems, and revenue-recycling design is not captured. This is a data limitation noted in Section 3.2 rather than a claim of a fully harmonised effective carbon price across countries.

Table A1. Sample Countries and Average Statutory Carbon Tax Rate, 2019–2024.

Country	Region	Avg. Carbon Tax (USD/tCO ₂ e)
Sweden	Europe	126.2
Switzerland	Europe	111.8
Finland	Europe	64.5
Norway	Europe	63.7
France	Europe	50.0
Portugal	Europe	43.2
Ireland	Europe	41.5
Canada	Americas	36.2
Denmark	Europe	26.8
United Kingdom	Europe	26.7
Argentina	Americas	10.0
South Africa	Africa	8.5
Singapore	Asia	6.3
Chile	Americas	5.0
Japan	Asia	3.0
Mexico	Americas	3.0

Source: World Bank Carbon Pricing Dashboard; authors' calculations.

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