Electrification Strategy, Carbon Intensity, and Firm Value: Korean and Japanese Automakers

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Korean and Japanese automakers have taken strikingly different paths into the electric age. Hyundai Motor Group moved early into battery electric vehicles (BEVs), while Toyota and its peers—path-dependently committed to hybrids—rationally delayed. We ask whether this divergence produced a measurable gap in carbon emission intensity (CEI), whether the gap is reflected in firm value, and whether the EU Emissions Trading System (ETS) carbon price sharpens the link between the two. Using a panel of three Korean and eight Japanese listed automakers over 2019–2024 (66 firm-year observations), we estimate an event-study difference-in-differences specification for the CEI gap and two-way fixed-effects regressions for firm value. The Korea–Japan CEI gap widens sharply in 2021, the year of IONIQ 5 production ($\delta\_2021 = -5.30$, $p = 0.010$), and fades by 2024 as Japanese OEMs launch their own BEVs—the delay-then-follow profile that path dependence predicts. The short-run gap operates through the revenue-composition channel rather than plant-level emission cuts. The ETS × CEI interaction is flat for Tobin's Q but significantly negative for ROA ($\beta = -0.0000376$, $p = 0.003$), though this result is sensitive to the CEI measure and should be read as suggestive. Carbon risk thus appears to hit realized earnings before it is written into market valuations.

Keyword: Electrification strategy, Carbon emission intensity, ESG, Event-study difference-in-differences, EU Emissions Trading System

Ⅰ. Introduction

The global automotive industry is caught between two forces. Battery electric vehicles are overtaking the internal combustion engine as the default technology, and carbon regulation—most visibly in the European Union—is tightening faster than many firms can adjust. At that intersection, the old question of how quickly to bet on a new powertrain is no longer just a product decision.

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It is also a financial one, because the speed of the bet feeds directly into a firm's carbon intensity and, through it, into valuation.

Korean and Japanese automakers have responded to this pressure in almost opposite ways. Hyundai Motor Group unveiled its dedicated BEV platform, E-GMP, in December 2020, and began selling the IONIQ 5—the first production model built on that platform—in February 2021. Toyota and most of its domestic peers took the other road. Armed with more than twenty million cumulative sales of hybrid vehicles and a deep supplier network built around them, they chose to keep a multi-pathway strategy that preserves current profitability. Whether this divergence has shown up in measurable carbon intensity differences, and whether capital markets have priced those differences, is an open question.

We address it through three hypotheses. H1 asks whether Korean automakers' CEI fell significantly below that of their Japanese peers after the E-GMP unveiling and IONIQ 5 launch. H2 asks whether lower CEI is reflected in higher firm value, measured by Tobin's Q and return on assets (ROA). H3 asks whether a higher EU ETS carbon price amplifies any adverse effect of CEI on firm value.

Our identification strategy differs from much of the existing literature in two ways. Rather than treating Korea's BEV turn as a response to a single regulatory event such as the EU Green Deal of December 2019, we read it as a compound event: Tesla's Model 3 entry into Korea in August 2019 created a visible demand shock, E-GMP and IONIQ 5 production in late 2020 and early 2021 supplied the matching response, and the EU's Green Deal, Fit-for-55 (July 2021), and CBAM (October 2023) shaped the regulatory backdrop. We also set aside the static two-by-two DID in favor of an event-study specification, which traces the gap year by year and makes the parallel-trends assumption directly testable.

The main findings are briefly these. The Korea–Japan CEI gap opens up in 2021 ($\delta\_2021 = -5.30$, $p = 0.010$), persists more weakly through 2022, and narrows by 2024. Evidence on the CEI–firm value link is specification-dependent and modest in magnitude. The moderation result is sharper but asymmetric: higher carbon prices depress ROA for higher-CEI firms ($\beta\_interaction = -0.0000376$, $p = 0.003$) but leave Tobin's Q essentially untouched. The ROA result is sensitive to the choice of CEI measure, so we treat it as suggestive. Taken together, these findings hint that realized earnings absorb carbon risk before equity valuations do.

The rest of the paper is organized as follows. Section II reviews the theoretical background and prior work. Section III develops the hypotheses. Section IV describes the data and empirical strategy. Section V reports the results. Section VI concludes.

Ⅱ. Theoretical Background and Prior Literature

2.1 Structural Background of Korea–Japan Electrification Divergence

The divergence between Korean and Japanese automakers did not begin with EU policy; it rests on older structural differences that organization theory has long studied under the headings of path dependence and incumbent inertia. Capabilities that yield success in one technological regime tend to harden into “competency traps” (Levitt and March, 1988) and “core rigidities” (Leonard-Barton, 1992) when the regime shifts, and incumbents systematically underinvest in discontinuous alternatives because their resource-allocation processes remain tied to existing customers and assets (Christensen and Bower, 1996; Gilbert, 2005). Toyota introduced the Prius in 1997 and has since sold well over twenty million hybrids, building not only a sizable technology licensing business but also a supplier ecosystem specifically designed around hybrid powertrains. Wu et al. (2014) formalize why such positions persist: complementary assets act as both “pipes” that buffer incumbents from technological change and “prisms” through which they evaluate it, so that a complement-preserving trajectory—here, hybrids—can be the ex ante rational choice even when a complement-disrupting trajectory—battery electric vehicles—is more likely to be favored by the market. On this account, the reluctance of Japanese OEMs to abandon hybrids is rational asset preservation rather than simple organizational failure; its predictable cost is delay rather than permanent paralysis.

Korea faced a different starting position. Without a comparable hybrid installed base, Hyundai Motor Group held few complementary assets worth preserving, which in Wu et al.’s (2014) terms removed both the buffer and the bias that keep incumbents on a complement-preserving path. A combination of vertical integration into battery sourcing—through LG Energy Solution, SK On, and Samsung SDI—and policy support for hydrogen and BEVs created the conditions for a platform leap rather than an incremental upgrade. The E-GMP unveiling in December 2020 and the IONIQ 5 launch two months later marked the point at which that leap became visible on the production floor. The Korea–Japan pairing therefore offers a rare quasi-natural contrast in how heterogeneous complementary-asset positions translate into divergent trajectory choices during a competence-destroying transition (Tushman and Anderson, 1986)—a contrast whose logic extends beyond automobiles to any industry in which an installed technology base confronts a discontinuous low-carbon alternative.

A natural question for the empirical design is why a divergence in vehicle architecture would show up in Scope 1+2 carbon intensity, which captures what happens inside the factory rather than on the road. Three channels link the two, and they operate on different time horizons. The first two are slow-moving supply-side channels: BEV assembly does not require the engine-machining, transmission-machining, and exhaust lines that are among the most energy-intensive parts of a conventional plant, and firms that commit early to BEV leadership tend to bundle the product transition with plant-level decarbonization—on-site renewable generation, RE100 power purchase agreements, process electrification, and energy-efficiency retrofits. Both require capacity conversion and capital investment, so their effect on measured CEI accrues over several years rather than within the launch year. The third channel is fast-moving and operates through the denominator: as BEV volumes rise, a larger share of a firm's revenue is generated by premium-priced, lower-emission vehicle lines, which mechanically pulls down revenue-normalized CEI even before anything changes at the legacy ICE plant. This composition channel is the one most plausibly capable of moving firm-level CEI in the first 1~2 years after a platform launch, and we test this prediction directly by decomposing the event-study result into its numerator and denominator components in Section V.

2.2 Theoretical Foundations of the Causal Chain

Three theoretical strands support the causal chain we test. Legitimacy theory (Suchman, 1995) and stakeholder theory (Freeman, 1984) provide the backbone for H2: firms with lower carbon intensity tend to attract ESG-oriented institutional investors and face a lower cost of equity (Dhaliwal et al., 2011), and they are less exposed to the upstream costs of CBAM-covered inputs such as steel and aluminum. Together these channels generate the firm-value premium that H2 is meant to pick up. In the Korean setting, Kim et al. (2021) documented a moderating role for consumer awareness in the ESG–firm-value relationship, and the moderation regression we use for H3 borrows directly from that structure.

The second strand, signaling theory (Spence, 1973), underwrites H3. When the carbon price is low, a high-CEI firm carries only a weak adverse signal about future cost exposure. As the price rises, the same firm-level CEI translates into a much stronger signal, and the penalty for being on the wrong side of the distribution grows with the price itself.

The third strand is the empirical carbon-premium literature. Bolton and Kacperczyk (2021) showed that firms with higher emissions earn higher expected returns—evidence that investors demand compensation for future regulatory risk—and Hsu et al. (2023) documented a related 4.42% annual premium associated with toxic emissions intensity. Krueger et al. (2020) complemented this with survey evidence that many institutional investors themselves feel climate risk is not yet fully reflected in equity prices. We revisit that perception in the specific setting of Korea - Japan automakers, where the ROA and Tobin's Q results diverge in an informative way.

2.3 The Compound Regulatory Context of EU Carbon Policy

EU carbon policy is not a single instrument but a layered system that has tightened substantially over the sample period. The Green Deal of December 2019 set the long-run target of climate neutrality by 2050. Fit-for-55, announced in July 2021, gave that target an operational edge by committing to a 55% reduction in emissions by 2030. The EU ETS, which has been in place since 2005, did much of the mechanical work: the allowance price rose from about €24 per tonne in 2019 to roughly €81 in 2022, translating directly into operating-cost pressure for EU-regulated entities and indirect supply-chain pressure for non-EU exporters.

The Carbon Border Adjustment Mechanism (CBAM) extends carbon pricing across the EU border. Its transitional phase began in October 2023, with full pricing scheduled for January 2026. A more recent proposal, COM (2025) 989 final, announced on 17 December 2025 (European Commission, 2025), would extend CBAM to downstream products—including automotive components—with implementation targeted for 2028. Because this last step postdates our sample period, we do not use it as an explanatory variable; it appears only as part of the policy backdrop against which our findings should be read.

2.4 Prior Literature and Research Gaps

The empirical literature linking carbon emissions to firm value has grown quickly. Bolton and Kacperczyk (2021) documented a carbon premium in U.S. equities, and Hsu et al. (2023) reported a 4.42% annual pollution premium for firms with high toxic-emissions intensity. Earlier, Dhaliwal et al. (2011) showed that voluntary nonfinancial disclosure reduces the cost of equity, and more recently Sautner et al. (2023) used earnings-call texts to build firm-level climate-risk exposure measures that correlate with green jobs, green patents, and option prices. On the direct effects of carbon pricing, Veith et al. (2009) found that the launch of ETS Phase 1 produced positive stock-price responses in European electric utilities.

The Korean-context literature has also accumulated in parallel. Park et al. (2025) constructed a climate policy uncertainty index for Korea over 2003–2022 and found that rising uncertainty depresses corporate investment and R&D, with the adverse effect concentrated in firms with high greenhouse-gas emissions—evidence that carbon exposure conditions how Korean firms absorb climate-policy signals. Park and Han (2021) examined how ESG activities shape corporate image and consumer responses among Korean firms. Kim et al. (2021) showed that consumer awareness moderates the ESG–firm-value relationship—structurally, a close cousin of the moderation regression we use in H3. Closest to our setting, Park et al. (2024) treated the 2015 introduction of the Korean ETS (K-ETS) as an exogenous shock and, using a DID design, found that treated firms did not actually reduce emissions but saw their environmental ratings improve; ROA rose modestly, while firm value fell significantly and systematic risk increased. That pattern—carbon regulation being absorbed at different speeds by different financial metrics—is precisely what we document here, only in a cross-country setting and under a different regulatory vector.

Despite this growing body of work, three gaps remain. None of the existing studies reads the automotive electrification divergence as a compound event and traces the CEI gap year by year. None examines the Korea–Japan comparison as a causal pathway from carbon intensity to firm value. And none jointly analyzes how Tobin's Q and ROA respond differently once a carbon price is introduced as a moderator. Our paper is organized around closing these three gaps within a single empirical framework.

Ⅲ. Hypotheses

The three hypotheses together describe a single causal chain. H1 asks whether the electrification divergence has in fact opened a CEI gap over time. H2 asks whether that gap shows up in firm value. H3 asks whether the EU ETS carbon price sharpens the link between CEI and value.

3.1 H1 — Divergence Confirmation: CEI Gap Widening After E-GMP Production

The theoretical logic of Section II.1 yields a directional prediction. When a competence-destroying transition arrives, the firm with weak complementary-asset commitments to the old technology moves first onto the disruptive trajectory, while the firm whose capabilities are locked into the old regime delays—rationally preserving its assets even as the gap opens (Levitt and March, 1988; Leonard-Barton, 1992; Wu et al., 2014). Applied to our setting, the path-dependent asymmetry between Korean and Japanese OEMs implies that, once Korea's BEV commitment materialized in production (E-GMP, December 2020; IONIQ 5, February 2021), the carbon intensity of the unencumbered first movers should fall relative to that of the encumbered incumbents—and, because rigidity delays rather than permanently blocks transition, the gap should be largest immediately after the commitment and narrow as incumbents follow. Empirically, we trace this prediction with an event-study design: the reference year is 2020, the normal state immediately before E-GMP was unveiled, and we estimate a separate (Korea × Year_t) coefficient δ_t for 2019 and for each year from 2021 through 2024, using δ_2019 as the pre-trend test.

H1 (Divergence Confirmation). In a competence-destroying low-carbon transition, automakers with weaker complementary-asset commitments to the incumbent powertrain technology reduce their carbon emission intensity faster than automakers whose capabilities are path-dependently committed to that technology, once the former's alternative-technology commitment materializes in production.

3.2 H2 — Value Transfer: CEI and Firm Value Premiums

H2 asks whether the CEI gap identified in H1 is visible in capital markets. Under legitimacy and stakeholder theories, lower-CEI firms should attract ESG-oriented capital, face a lower cost of capital, and carry less exposure to the upstream costs of CBAM-regulated inputs such as steel and aluminum—all channels that would lift firm value. We use Tobin's Q and ROA in parallel precisely because they measure different things: Tobin's Q captures market expectations, ROA captures realized profitability, and the two need not move at the same speed.

H2 (Value Transfer). Automakers with lower carbon emission intensity command higher firm value—in market expectations and in realized profitability—because lower carbon exposure attracts ESG-oriented capital, lowers the cost of capital, and reduces exposure to carbon-priced input costs.

3.3 H3 — Price Moderation: ETS Price and CEI–Value Amplification

H3 treats the EU ETS carbon price as an

outside signal that can amplify or mute the CEI–value link. Under signaling theory, a high-CEI firm looks only mildly exposed when the carbon price is low, but the same firm looks much more exposed once prices rise. The penalty built into firm value should therefore scale with the carbon price itself.

H3 (Price Moderation). A rising carbon price strengthens the negative relationship between carbon emission intensity and firm value, because the same level of carbon exposure conveys a stronger signal of future cost vulnerability when the price of carbon is higher.

Ⅳ. Data and Methodology

4.1 Sample and Period

Our sample covers eleven listed OEMs: three Korean firms—Hyundai Motor, Kia, and KGM—and eight Japanese firms—Toyota, Honda, Nissan, Suzuki, Mazda, Subaru, Mitsubishi, and Isuzu. The analysis period runs from fiscal year 2019 through 2024, so the panel is nominally balanced at sixty-six firm-years. In practice, it is unbalanced. KGM was in court receivership from 2020 through 2022, and its equity price and market capitalization are missing across the 2021–2022 trading-suspension window; a handful of ESG disclosure items are also missing at irregular intervals across other firms. We keep all eleven firms and run the main specifications on the full unbalanced panel, letting the estimators drop observations with missing regressors or dependent variables; the sample size for each specification is reported alongside the results in Tables 2 through 6. Two clarifications about KGM's role are in order, because the firm produces only internal- combustion vehicles for most of the sample window (its first domestic BEV, the Torres EVX, launched in September 2023) and is therefore not a BEV-strategy representative in the way Hyundai and Kia are. First, KGM discloses no emissions data, so it contributes zero observations to any CEI-based specification: the H1 treatment group consists entirely of Hyundai and Kia. Second, KGM enters only the firm-value samples (Tobin's Q, ROA), where it serves as a Korean control observation rather than a treated BEV firm; we report KGM-excluded versions of those specifications in the robustness section and the results are unchanged.

4.2 Data Sources and Reproducibility

All financial, ESG emissions, equity-price, market-capitalization, and foreign-exchange data come from a single commercial financial database, LSEG Workspace, formerly Refinitiv Eikon (LSEG, 2025). We take financial statements at fiscal year end, sum Scope 1 and Scope 2 for the emissions variable, and convert all monetary values to U.S. dollars at the fiscal year-end exchange rate so that firms can be compared on a common basis. The EU ETS price is the annual average of daily closing prices for the one-month-ahead EUA futures contract (CFI2c1), and country-level electricity-grid carbon intensity is drawn from Ember Climate (2024).

Variable construction is traceable end to end. The specific database fields, query parameters, and processing steps are documented in the analysis scripts provided in the online appendix, so the entire pipeline can be reproduced from source.

4.3 Empirical Models

4.3.1 H1: Event-Study Dynamic DID (Baseline = 2020)

$$CEI\_it = \alpha + \Sigma\_\{t \in \{2019, 2021, 2022, 2023, 2024\}\} \ \delta\_t \cdot Korea\_i \cdot 1\{Year\_it = t\} + \gamma\_1 \cdot Lev\_it + \gamma\_2 \cdot lnAssets\_it + \mu\_i + \lambda\_t + \varepsilon\_it$$

The baseline year is 2020, the normal state immediately before E-GMP, and δ_t picks up the Korea - Japan gap in each non-baseline year. The indicator 1{Year_it = t} equals one when an observation's year is t. Korea_i is a time-invariant country dummy and is therefore absorbed by the firm fixed effect μ_i; year dummies are absorbed by λ_t. What remains identified is the set of inter-

〈Table 1〉 Variable Definitions and Measurement

Category	Variable	Symbol	Definition / Formula	Unit
DV (H1)	Third-party standardized CEI	CEI_std	Total CO_2 emissions to revenues (USD million), database-reported	tCO_2 e/USD mn
DV (H1)	Directly computed CEI	CEI_calc	Scope 1+2 emissions ÷ revenue (USD million)	tCO_2 e/USD mn
DV (H2, H3)	Tobin's Q	TobQ	(Market cap USD + Debt USD) ÷ Total assets USD	Ratio
DV (H2, H3)	Return on assets	ROA	Net income ÷ Average total assets	Ratio
H1 treatment	Korea dummy	Korea	1 if Korean firm, 0 if Japanese	Dummy
H1 timing	Post-E-GMP years	Year_t	Year indicator for 2021, 2022, 2023, 2024	Dummy
H3 moderator	EU ETS price	ETS	Annual mean of CFI2c1 closing price	EUR/tCO_2 e
Control	Leverage	Lev	Total debt ÷ Total assets	Ratio
Control	Firm size	lnAssets	ln(Total assets, USD million)	Log
Control	R&D intensity	R&D	R&D expenditure ÷ Revenue	Ratio
Instrument	Grid carbon intensity	Grid_CI	Country-year gCO_2 /kWh (Ember Climate)	gCO_2 /kWh

action coefficients δ_t. The significance of δ_2019 serves as our pre-trend test. To keep the sample intact and avoid the 2019- missingness pattern that some additional controls introduce, we include only leverage and ln(assets) as controls, and we cluster standard errors at the firm level.

4.3.2 H2: Two-Way Fixed-Effects Panel

$$FirmValue\_it = \beta\_0 + \beta\_CEI \cdot CEI\_it + \gamma\_k \cdot Controls\_it + \mu\_i + \lambda\_t + \varepsilon\_it$$

We compute Tobin's Q using the Chung and Pruitt (1994) approximation: (market capitalization + book value of debt) divided by book value of total assets. Our main specification uses a minimal control set—leverage and ln(assets)—and keeps N at 59. For robustness, we also estimate a fully controlled version that adds R&D intensity and revenue growth; that version loses observations and drops to N = 29, and we flag it as a conditional check rather than a primary result. Four combinations are reported throughout: Tobin's Q and ROA as the dependent variable, each paired with CEI_std and CEI_calc as the explanatory variable.

4.3.3 H3: Moderation Regression

$$FV\_it = \beta\_0 + \beta\_1 \cdot CEI\_c + \beta\_2 \cdot ETS\_c + \beta\_3 \cdot (CEI\_c \times ETS\_c) + Controls\_it + \mu\_i + (\lambda\_t) + \varepsilon\_it$$

CEI and the ETS price are both mean-centered. A two-way fixed-effects design would absorb ETS_c into the time fixed effects, so we estimate two versions in parallel: an EntityFE model that keeps ETS_c as a main effect (using only firm fixed effects), and a TwoWayFE model in which only the interaction survives. The quantity of interest is how the moderation effect differs between Tobin's Q and ROA.

4.3.4 Methodological Limitation: Failed 2SLS Instrumental-Variable Attempt

We initially tried a two-stage least squares (2SLS) estimation that used country-level grid carbon intensity (Ember Climate, 2024) as an instrument for CEI. The attempt failed: first-stage F-statistics fell below two (F = 1.90 for CEI_std, F = 1.33 for CEI_calc), well under the Stock - Yogo threshold of ten (Stock and Yogo, 2005), so we face a clear weak-instrument problem. Two things drive that outcome. First, Korean and Japanese grid carbon intensity happen to have converged to very similar levels—roughly 450 gCO_2 /kWh each – during our sample period, which leaves almost no cross-country variation for the instrument to exploit. Second, both countries show a monotonic decline in grid intensity from 2019 to 2024, so most of the remaining time variation is absorbed by year fixed effects. With neither source of variation strong enough to carry the identification, Grid_CI cannot function as a valid instrument. We therefore rely on the two- way fixed-effects panel as the primary design for H2 and H3, and we leave the search for instruments with adequate cross-country and time-series variation—for example, country-specific battery-raw-material prices or EU CBAM trade-exposure indices—for future work.

Ⅴ. Results

5.1 Descriptive Statistics

Table 2 reports descriptive statistics and group comparisons. Korean firms have a higher average Tobin's Q than their Japanese peers (1.469 vs. 0.954), and the difference is significant ($t = 2.574$, $p = 0.020$). CEI_std, our focal indicator, averages 24.04 tCO_2 e per USD million across the full sample. Variance inflation factors for all regressors remain below ten, so multicollinearity does not appear to be a concern.

5.2 H1 Test: Event-Study Dynamic DID

Table 3 presents the event-study estimates with 2020 set as the baseline. The pre-trend test gives δ_2019 values of −1.52 ($p = 0.533$) for CEI_std and +3.77 ($p = 0.151$) for CEI_calc−both statistically indistinguishable from zero−so the identifying assumption appears to hold.

〈Table 2〉 Descriptive Statistics and Group Comparisons

Variable	N	Mean	SD	Korea mean	Japan mean	t	p
Tobin's Q	65	1.094	0.501	1.469	0.954	2.574	0.020**
ROA	55	0.028	0.032	0.016	0.032	−1.315	0.206
CEI_std	59	24.04	7.57	23.09	24.45	−0.744	0.465
CEI_calc	59	23.30	8.48	23.17	23.34	−0.124	0.902
Scope 1+2 ($MtCO_2$ e)	59	1.90	1.93	1.81	1.98	−0.454	0.652
EU ETS (EUR)	66	55.45	24.11	55.45	55.45	–	–
Leverage	66	0.705	0.070	0.757	0.686	4.051	0.000***
ln(Total assets)	66	10.946	1.366	10.537	11.099	−1.240	0.228
ESG Score	59	72.17	11.34	75.48	70.96	1.724	0.099*
Grid CI	66	449.7	27.2	449.7	449.7	–	–

Note. Welch approximate two-tailed t-test. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. All financial figures are converted to U.S. dollars using fiscal year-end exchange rates. The EU ETS price and Grid CI are year-level time-series variables replicated across all 11 firms, so Korea - Japan group means are identical. For Grid CI, Korean and Japanese annual averages happened to converge to approximately 450 gCO_2 /kWh over 2019 - 2024, leaving very limited cross-country variation. Group-specific standard deviations and Welch degrees of freedom are omitted here for space and are reported in the online appendix.

〈Table 3〉 H1 Event-Study Results (DV: CEI, Baseline = 2020)

Year t	(1) CEI_std δ_t (SE)	(2) CEI_std p	(3) CEI_calc δ_t (SE)	(4) CEI_calc p
2019 (pre-trend)	−1.52 (2.42)	0.533	+3.77 (2.57)	0.151
2020 (baseline)	0 (ref.)	–	0 (ref.)	–
2021 (E-GMP)	−5.30 (1.97)	0.010**	−1.81 (3.61)	0.618
2022	−4.30 (2.31)	0.071*	+0.76 (2.74)	0.782
2023	−3.92 (2.59)	0.139	+1.90 (3.77)	0.617
2024	−0.93 (2.91)	0.752	+5.20 (3.91)	0.191
Controls	Lev + ln(assets)		Lev + ln(assets)	
Firm FE	Yes		Yes	
Year FE	Yes		Yes	
N	59		59	

Note. Firm-clustered standard errors. δ_t denotes the coefficient on (Korea × Year_t). Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

For CEI_std, the event-study coefficient is sharply negative in 2021, the first year after E-GMP production began (δ_2021 = −5.30, p = 0.010). In plain terms, Korean firms' carbon intensity in 2021 fell by an additional 5.30 tCO_2 e/USD million relative to Japanese peers compared with the 2020 baseline. The effect holds into 2022 at marginal significance (δ_2022 = −4.30, p = 0.071) and then fades, with δ_2024 statistically indistinguishable from zero (−0.93, p = 0.752). A natural reading of that arc is that Japanese OEMs began their own BEV transitions later, which gradually narrowed the gap.

CEI_calc tells a different story: the same event produces no significant negative coefficient. The likely culprit is exchange-rate movement. CEI_calc puts Scope 1+2 emissions over USD-converted revenue, so the won's depreciation after 2022—from 1,165 KRW/USD in 2019 to 1,363 in 2024—mechanically lowered the USD-denominated portion of Korean revenue and pushed CEI_calc up even when underlying emissions were falling. The third-party-standardized CEI_std uses a different currency-adjustment convention and appears more insulated from this distortion, which makes it a better proxy for the underlying strategic divergence. We come back to this measurement issue in the robustness section.

To probe what lies behind the CEI_std result—and to address directly whether a brand-new vehicle platform could plausibly move firm-level carbon intensity within its launch year—we decompose the event-study estimate into its numerator and denominator components. CEI is a ratio of Scope 1+2 emissions to revenue, so the year-specific

〈Table 4〉 Decomposition of the H1 Event-Study Result and COVID-Shock Robustness

Specification (DV)	δ_2021	p	δ_2022	p	N
(1) CEI_std (baseline)	−5.30	0.010**	−4.30	0.071*	59
(2) ln(Scope 1+2) − numerator	−0.03	0.803	−0.00	0.982	59
(3) ln(Revenue USD) − denominator	+0.15	0.150	+0.03	0.614	66
(4) CEI_std, revenue-growth control	−5.46	0.029**	−4.62	0.149	49

Note. Firm-clustered standard errors; firm and year fixed effects; controls include leverage and ln(assets) throughout. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Row (4) adds contemporaneous revenue growth as a control; because revenue growth is undefined for 2019, the pre-trend coefficient is not estimable in that specification and post-treatment coefficients are reported from the 2020 baseline.

Korea - Japan gap can originate in the emissions numerator, the revenue denominator, or both. Table 4 reports event studies run separately on ln(Scope 1+2) and ln(revenue in USD), alongside the baseline and a specification that adds contemporaneous revenue growth as a control.

The decomposition is informative in both directions. The emissions numerator shows no significant Korea - Japan divergence in any year (row 2: δ_2021 = −0.03, p = 0.803)—plant-level Scope 1+2 emissions did not fall measurably faster in Korea immediately after E-GMP production began. This is exactly what the mechanism discussion in Section II.1 predicts: converting assembly capacity and decarbonizing plants are multi-year supply-side processes, not launch-year events. The action is instead on the revenue side: Korean firms' USD revenue rose by roughly 15 percent relative to Japanese peers in 2021 (row 3), short of conventional significance but directionally consistent with the composition channel, in which premium-priced BEV lines—IONIQ 5 averaged well above Hyundai's portfolio mean transaction price—expand the revenue base faster than emissions grow. The short-run CEI gap, in other words, is a composition- channel phenomenon, and the supply-side channels remain a prediction about longer horizons rather than a finding of this paper.

The revenue-side locus of the effect raises a natural alternative explanation: 2021 - 2022 coincided with the COVID-19 recovery and the semiconductor shortage, so the gap could in principle reflect asymmetric pandemic-era revenue shocks rather than electrification strategy. Three pieces of evidence weigh against this reading. First, when contemporaneous revenue growth is controlled directly (row 4), the 2021 coefficient survives essentially unchanged (δ_2021 = −5.46, p = 0.029)—the gap is not absorbed by differences in revenue momentum. Second, the chip shortage hit both countries' producers: industry-wide losses were estimated at roughly 10.5 million units in 2021 by industry supply-chain forecasters, Toyota announced a cut in its fiscal-2022 output target from 9.7 to 9.2 million units, and Hyundai's own disclosed total sales had fallen 15.4 percent in 2020; these figures come from the companies' production announcements and contemporaneous industry analyses of the semiconductor shortage. Third, and most tellingly, the firm that absorbed the largest revenue shock in the sample—Nissan, whose global sales fell 20.7 percent in 2022—exhibited no Korean-style BEV expansion, which is difficult to reconcile with a shock-driven account but follows naturally from a strategy-driven one.

Firm-level electrification data corroborate the strategic reading. Drawing on the automakers' own monthly and annual sales disclosures—Hyundai and Kia report BEV shipments on a wholesale basis, Toyota reports electrified sales by powertrain type—we compile each firm's BEV share of global sales. Hyundai's global BEV share (wholesale basis) rose from 3.1 percent in 2021 to 4.9 percent in 2022 and 6.2 percent in 2023, and Kia's from 3.1 to 5.1 percent over the same window, while Toyota's remained below 1 percent through 2023 (reaching 0.9 percent only that year) even as its hybrid sales exceeded 2.6 million units in 2022. No Japanese OEM in the sample exceeded a 3 percent BEV share before 2023. The ordering of product-platform launches matches: Toyota's first dedicated BEV (bZ4X) and Nissan's Ariya reached the market in mid-to-late 2022, roughly one and a half to two years after IONIQ 5—the same lag at which the estimated CEI gap begins to close. The fade of δ_t after 2022 is therefore not an anomaly for the path-dependence account but its second prediction: rigidity delays transition rather than preventing it, and the delay—not permanence—is what the event-study profile measures. One observation on sample composition belongs here: KGM, the third Korean firm, discloses no emissions data and therefore contributes zero observations to any CEI specification; the Korean treatment group in H1 consists of Hyundai and Kia, the two firms whose BEV commitment the treatment is meant to capture.

5.3 H2 Test: CEI and Firm Value

H2 gives specification-dependent answers. In the main specification with minimal controls ($N = 59$), β_{CEI} is not significant for either dependent variable—Tobin's Q yields $\beta = +0.0002$ ($p = 0.945$), and ROA yields $\beta = +0.0009$ ($p = 0.360$)—so H2 is not supported there. The fully controlled specification ($N = 29$) flips the Tobin's Q coefficient: $\beta_{CEI} = -0.00614$ with $p = 0.043$.

The most plausible reason for the divergence between the two results is selection. Adding R&D intensity (missing for

〈Table 5〉 H2 Results: Two-Way Fixed-Effects Panel (Main + Fully Controlled)

Variable	(1) TobQ main	(2) TobQ full	(3) ROA main	(4) ROA full	(5) TobQ full (calc)
CEI (β_CEI)	+0.00019	−0.00614**	+0.00091	−0.00176	−0.00300
(p-value)	(0.945)	(0.043)	(0.360)	(0.451)	(0.134)
Leverage	Yes	Yes	Yes	Yes	Yes
ln(Assets)	Yes	Yes	Yes	Yes	Yes
R&D intensity	—	Yes	—	Yes	Yes
Revenue growth	—	Yes	—	Yes	Yes
Firm & Year FE	Yes	Yes	Yes	Yes	Yes
N	59	29	49	29	29

Note. ** $p < 0.05$. Parentheses report p-values. Firm-clustered standard errors. The main specification (N = 59) parallels the fully controlled specification (N = 29). The main-specification N = 59 excludes observations with missing CEI data from the Table 2 Tobin's Q N = 65 (largely due to 2019 ESG disclosure gaps). The ROA main N = 49 reflects additional partial missingness in leverage/ln(assets) controls. The fully controlled N = 29 further excludes observations missing R&D intensity (Kia across years) and revenue growth (all of 2019).

Kia) and revenue growth (missing for all of 2019) cuts the sample to 29 observations drawn mostly from Japanese OEMs and the years 2020–2024. When significance only appears in this restricted sub-sample, the external validity of the result is limited. We therefore treat the main specification as our primary report and the fully controlled specification as a supplementary observation, not a confirmation.

The sign flip from $\beta = +0.00019$ in the main specification to $\beta = -0.00614$ in the fully controlled one—thirty times larger in magnitude and in the opposite direction—coincides with both the addition of new controls and the shrinking of the sample, which raises two additional possibilities. One is suppression: if R&D intensity is correlated with CEI (for example, because high-emission firms invest aggressively in low-carbon R&D), adding it can reveal a negative CEI coefficient that was otherwise masked. VIFs below ten rule out severe multicollinearity, but confidence intervals widen noticeably in the smaller sub-sample. The other is simply small-sample bias: 29 observations are too few to identify firm-by-year two-way fixed effects reliably. Reading these together, we position the fully controlled significance as a conditional finding rather than robust support for H2.

Why does the main specification fail to deliver on H2? The most obvious candidate is statistical power: with eleven firms and N = 59, a genuine carbon premium could easily remain undetected. A second possibility is that capital markets have not yet fully priced the Korea–Japan CEI differential. Bolton and Kacperczyk (2021) documented the carbon premium primarily in large U.S.

〈Table 6〉 H3 Results: ETS × CEI Moderation Regression

Variable	(1) TobQ EntityFE	(2) TobQ TwoWayFE	(3) ROA EntityFE	(4) TobQ robust (calc)	(5) ROA robust (calc)
CEI_c × ETS_c (β_int)	−0.000012	−0.000025	−0.0000376***	+0.000004	−0.0000019
(p-value)	(0.675)	(0.475)	(0.003)	(0.890)	(0.945)
ETS_c (main)	Yes	Absorbed	Yes	Yes	Yes
CEI_c (main)	Yes	Yes	Yes	Yes	Yes
Controls	Lev+lnA	Lev+lnA	Lev+lnA	Lev+lnA	Lev+lnA
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	No	No
N	59	59	49	59	49

Note. *** $p < 0.01$. Parentheses report p-values. In TwoWayFE, ETS_c is fully absorbed by year fixed effects. The ROA-DV specification with N = 49 reflects exclusion of observations missing leverage/ln(assets) beyond the Table 2 ROA N = 55. A TwoWayFE specification for ROA is omitted because, with ETS_c fully absorbed by year fixed effects and the small sample size, the interaction term alone does not support stable identification; the EntityFE specification serves as the primary identification for H3 on ROA.

firms, and it would not be surprising if that pricing showed up more slowly among Asian OEMs.

5.4 H3 Test: ETS Price Moderation

H3 produces one of the more interesting patterns in the paper. When Tobin's Q is the dependent variable, the CEI × ETS interaction is not significant (EntityFE: $\beta = -0.000012$, $p = 0.675$). When ROA is the dependent variable, the interaction is sharply negative ($\beta = -0.0000376$, $p = 0.003$). On the realized-profitability side, then, higher carbon prices do amplify the adverse effect of CEI, which is the pattern H3 predicts. The result, however, depends on how CEI is measured: it holds for CEI_std but disappears for CEI_calc ($\beta = -0.0000019$, $p = 0.945$). We read this two-indicator inconsistency as a signal that the finding is sensitive to measurement choice—a fragile result rather than robust support—and we interpret it accordingly. The two measures differ mainly in how they adjust for exchange-rate variation (see the robustness discussion, item ②), so the reliability of the ROA result ultimately rests on which indicator better captures the underlying economic concept of CEI.

The split between Tobin's Q and ROA is itself informative about how carbon risk flows into financial statements. ROA captures realized profitability, so the cost disadvantage that high-CEI firms face—higher energy bills, greater regulatory compliance cost—feeds through quickly once the carbon price rises. Tobin's Q reflects forward-looking market expectations, and a number of factors could slow its response: investors may not yet fully price the CEI × carbon-price interaction, or the signal may be diluted by firm size and R&D intensity. Krueger et al. (2020) documented exactly this perception among institutional investors, who report that climate risk is not yet fully built into equity valuations. Our evidence from Korea–Japan automakers is consistent with that view: carbon risk shows up in realized earnings first, and has not yet moved to market valuations in the same way.

A useful contrast is Park et al. (2024), who examined the 2015 K-ETS introduction. Their result—ROA up modestly, firm value down significantly—points in the opposite direction: profitability rises while valuation falls. In our Korea–Japan automaker sample, ROA shows a moderation effect while Tobin's Q does not. The contrast suggests that the pathway carbon regulation takes into firm financials depends on several factors: whether the regulation is domestic and direct or extraterritorial and indirect; whether the sample is economy-wide or an industry as specific as automotive OEMs; and which window one is looking at—K-ETS Phase 1 over 2015–2017 or the EU ETS price surge of 2019–2024. Put together, the two studies support a broader observation: carbon regulation is absorbed into profitability and firm value at different speeds, and the ranking between them is not fixed.

5.5 Robustness

① **KGM inclusion and exclusion.** Because KGM's equity price and market capitalization are missing for 2021–2022 during its trading suspension, Tobin's Q specifications return essentially the same estimates whether KGM is included or excluded. H1, H2, and H3 results are therefore not driven by KGM's unusual legal status.

② **The CEI_std and CEI_calc split.** H1 results diverge between the two CEI measures, and the most plausible explanation is the exchange-rate distortion discussed in the H1 results (Section V.2). The strong CEI_std result (δ_2021 $p = 0.010$) versus the flat CEI_calc result (δ_2021 $p = 0.618$) is consistent with CEI_std capturing the underlying strategic divergence more accurately. We treat this both as a methodological contribution and as a caution for future cross-country carbon-metric research. That environmental ratings can diverge systematically with the measuring entity and the industry classification applied is consistent with prior evidence: Choi and Kim (2023) show that discrepancies between Korean and global ESG ratings are driven more by sectoral classification than by financial factors, underscoring that the choice of measurement convention is not innocuous in cross-country comparison.

③ **The 2SLS attempt.** As noted earlier, we tried to instrument CEI using Ember grid carbon intensity, but the first-stage F-statistic fell below two—well under the Stock–Yogo threshold of ten (Stock and Yogo, 2005)—and the instrument failed. The underlying reason is that Korean and Japanese grid intensities converged to roughly 450 gCO/kWh during our sample, leaving little cross-country variation, and the remaining time trend is absorbed by year fixed effects. We therefore rely on the two-way fixed-effects panel for identification and flag the search for a stronger instrument as future work.

5.6 Synthesis of Results

Taken together, the three hypotheses produce a coherent but uneven picture. H1 is supported with a clean dynamic arc—a strong negative shock at 2021 (5% level), marginal persistence into 2022 (10% level), and fading by 2023–2024, with the pre-trend test passing—and the decomposition locates the short-run gap in the revenue-composition channel rather than in plant-level emissions, with the effect surviving a direct control for contemporaneous revenue growth. H2 is genuinely mixed—insignificant in the main specification and only conditionally significant in the fully controlled one, where selection concerns limit what we can claim. H3 is the most striking single result:

〈Table 7〉 Hypothesis Test Summary

Hypothesis	Key evidence	Coefficient	p-value	Verdict	Notes
H1	δ_2021 (E-GMP year)	−5.30	0.010**	Supported	Pre-trend passed
H1	δ_2022 (persistence)	−4.30	0.071*	Marginally supported	Fades after 2023
H1	δ_2019 (pre-trend)	−1.52	0.533	Passes	DID identification valid
H2	TobQ ~ CEI, main spec.	+0.00019	0.945	Not supported	N = 59
H2	TobQ ~ CEI, fully controlled	−0.00614	0.043**	Conditionally support.	N = 29; selection concern
H3	TobQ interaction	−0.000012	0.675	Not supported	Market expectations
H3	ROA interaction ★	−0.0000376	0.003***	Supported (fragile)	Sensitive to CEI measure

Note. ★ Our main finding. ***, **, * denote 1%, 5%, and 10% significance levels, respectively. "Conditionally supported" indicates that statistical significance is contingent on sample selection or measurement choice and should be interpreted with caution rather than as robust support.

a strongly negative ETS × CEI interaction for ROA (β_int = −0.0000376, $p = 0.003$), and no comparable effect for Tobin's Q. But that ROA result holds only for CEI_std, not CEI_calc, so we read it as a fragile finding rather than robust support. The broader pattern—if we allow ourselves the inference—is that carbon risk is starting to appear in realized profitability well before it is priced into market valuations.

Ⅵ. Conclusion and Implications

6.1 Summary of Main Findings

We set out to ask whether the divergent electrification strategies of Korean and Japanese automakers have produced a measurable CEI gap, whether that gap is reflected in firm value, and whether the EU ETS carbon price sharpens the link between the two.

On the first question, the evidence is clear and, with the decomposition, more precise than before. In 2021, the first year after Hyundai Motor Group's E-GMP unveiling and the IONIQ 5 launch, Korean firms' CEI fell by an additional 5.30 tCO_2 e/USD million relative to Japanese peers from the 2020 baseline ($p = 0.010$), persisting marginally into 2022 ($p = 0.071$) and fading by 2024. Decomposing the ratio shows that the short-run gap operates through the revenue-composition channel—premium-priced BEV lines expanding the revenue base—rather than through immediate plant-level emission cuts, and the effect survives a direct control for contemporaneous revenue growth. The full arc, opening and then closing as Japanese OEMs launched their own dedicated BEVs roughly two years later, is what a path-dependence account predicts: complementary-asset commitments delay an incumbent's transition rather than preventing it, and the delay is precisely what the event-study profile measures.

The second question is less settled. H2 is not supported in the main specification and is only conditionally supported in the fully controlled one—a pattern that could reflect either incomplete pricing of the Korea–Japan CEI difference by capital markets or simply limited statistical power in a small sample. The third question produces the paper's most interesting finding: a null result for Tobin's Q and a strongly negative interaction for ROA (β_int = −0.0000376, $p = 0.003$), suggesting that higher carbon prices translate high CEI into a realized-profitability penalty. Because the ROA result holds only for CEI_std and not CEI_calc, though, it is sensitive to how CEI is measured and should be read with that caveat in mind.

6.2 Theoretical Contributions

We see three contributions. The first is interpretive: rather than treating Korea's BEV turn as a response to a single regulatory event—the EU Green Deal being the usual candidate—we read it as a compound event in which Tesla's Model 3 entry into Korea in August 2019 supplied a demand shock, E-GMP and IONIQ 5 production in late 2020 and early 2021 supplied the matching response, and the EU Green Deal, Fit-for-55, and CBAM formed the regulatory backdrop. That framing offers a sharper account of what actually triggered the strategic divergence, and it is portable to other settings where policy and technology events overlap.

The second contribution is empirical. We document that carbon risk moves through Tobin's Q and ROA at different speeds. In particular, the combination of a significant ROA moderation effect and a null Tobin's Q effect is consistent with realized profitability pricing carbon risk ahead of market valuation—a pattern that lines up with Krueger et al.'s (2020) survey evidence that institutional investors themselves feel climate risk is not yet fully reflected in equity prices. Park et al.'s (2024) finding under K-ETS—ROA up, firm value down—fits the same broader picture, and our study extends that observation along two new axes: a cross-country comparison between Korea and Japan, and a bifurcation between BEV and HEV strategies. The approach also complements Sautner et al.'s (2023) text-based measure of climate exposure by offering a financial-metric-based lens on the same underlying phenomenon.

The third contribution is methodological. The gap between third-party standardized CEI and directly computed CEI is not noise; it is a systematic exchange-rate distortion that any cross-country carbon study is likely to face. Flagging this distortion—and showing how much the H1 and H3 results depend on which measure is used—is itself a contribution to how cross-country carbon metrics should be constructed and interpreted.

6.3 Practical Implications

Several practical observations follow from the results, though we want to keep them tied to what the evidence actually shows rather than stretching them beyond it.

For investors and asset managers. The moderation effect in ROA ($\beta\_int = -0.0000376$, $p = 0.003$) suggests that EU ETS pricing is already feeding through the realized profitability of Korean and Japanese automakers, while Tobin's Q shows no parallel effect. Three concrete steps follow. First, screen automotive holdings on earnings-based carbon metrics—CEI interacted with the prevailing carbon price—rather than on valuation multiples alone, since the latter do not yet embed the interaction in this sample. Second, when comparing carbon intensity across firms reporting in different currencies, use a third-party standardized CEI measure or recompute intensities at constant exchange rates; our results show that raw revenue-normalized CEI can move materially on FX alone. Third, treat the January 2026 CBAM pricing launch as a scheduled event for re-estimating the ROA channel: if the profitability penalty steepens after full pricing begins, portfolio carbon-exposure limits for non-EU OEMs should tighten accordingly.

For Japanese automakers. The two- to three-year CEI gap that opened after E-GMP production carries a measurable lesson about the cost of complementary-asset preservation: the delay was visible to any counterparty tracking carbon metrics, including EU regulators and ESG-screened capital. Managerially, this argues for decoupling the two rigidities Gilbert (2005) distinguishes—even where resource commitments to hybrid platforms remain rational, routine commitments need not follow. Practically: establish BEV-dedicated platform teams with separate capital budgets insulated from legacy-program hurdle rates; disclose a third-party standardized CEI alongside statutory emissions so that the composition effects of electrification become visible to investors as they accrue; and treat the 2028 CBAM downstream extension as the binding deadline by which component supply chains must carry verifiable embedded-carbon accounting.

For Korean firms. The same H1 results point to both a success and a warning. The CEI lead built through early BEV transition was real in 2021–2022 but had narrowed by 2024, and the decomposition shows the lead rested on the fast-moving composition channel rather than on plant decarbonization. The actionable implication is that the durable second-stage advantage must now come from the slow channels: convert the first-mover window into supply-side assets—renewable power purchase agreements and on-site generation at major plants, electrified paint and casting processes—before competitors' BEV ramps erode the composition advantage entirely; and report Scope 1+2 reductions and BEV-mix effects separately in sustainability disclosures, since bundling them invites exactly the measurement skepticism this paper documents.

For policymakers. Even though our Korea–Japan sample is not directly regulated by the EU ETS, the ETS price still exerts a moderating effect on ROA ($p = 0.003$), implying that EU carbon pricing reaches the realized profitability of firms outside its jurisdiction through exports, local production, and supply chains. Two design implications follow for Korean and Japanese policymakers. First, domestic carbon-price trajectories (K-ETS, GX-ETS) that lag the EU price do not insulate exporters—they merely shift where the cost is collected—so aligning domestic allowance prices and recognized accounting with CBAM methodology before the 2028 downstream extension would convert a compliance cost into an administrative one. Second, the measurement distortions we document argue for regulators to mandate currency-invariant intensity disclosure (emissions per vehicle or per constant-currency revenue) in sustainability reporting standards, so that cross-border carbon comparisons used in regulation do not inherit exchange-rate noise.

6.4 Limitations and Future Research

Several limitations deserve to be stated plainly, partly because they define the boundaries of what we can claim and partly because they mark the most natural directions for follow-up work.

The most obvious limitation is size. With eleven firms and sixty-six firm-years, our sample constrains the statistical power available to H2 and H3, and it limits the generality of any Korea–Japan comparison. A natural extension would add European OEMs (Volkswagen, BMW, Stellantis, Mercedes-Benz), U.S. OEMs (Tesla, GM, Ford), and Chinese OEMs (BYD, SAIC) to the panel, which would let the same questions be asked at a global scale.

A second set of limitations concerns identification. Our attempt to instrument CEI with grid carbon intensity produced F-statistics below two and had to be abandoned, so CEI endogeneity is imperfectly controlled even under our preferred specification. Future work should look for instruments with stronger cross-country and over-time variation—country-specific battery-cell supply-chain costs or the pace of renewable-electricity share growth are two candidates worth trying. The pre-trend test, which relies only on δ_2019, also limits what we can say about the shape of the pre-treatment trend; δ_2019 is statistically indistinguishable from zero, which supports identification, but an ideal test would use multiple pre-period years (2017, 2018) to establish linearity. Extending the time series backward is a task for a future iteration of the data set.

A third set of limitations concerns measurement and mechanism. Our CEI variable is built on Scope 1+2, the direct and indirect emissions that arise at the manufacturing stage. BEV transition also affects carbon intensity through Scope 3 Category

11—the use-phase emissions of vehicles sold—but Scope 3 accounting and disclosure are not yet consistent across Korean and Japanese OEMs, so constructing an internationally comparable panel on that basis is not yet feasible. Following the financial literature's standard convention (Bolton and Kacperczyk, 2021), we use Scope 1+2 as our main indicator, with the expectation that analysis including use-phase emissions will become possible as Scope 3 comparability improves. The H3 ROA result adds a second measurement caveat: it is reproduced with CEI_std but not with CEI_calc. We interpret the two measures as differing mainly in how they adjust for exchange-rate variation—and read CEI_std as the better-adjusted of the two—but that interpretation is itself a testable hypothesis. Constructing alternative measures that decompose the exchange-rate, cost, and revenue-composition components of cross-country CEI would be a useful step, and the fragility of our H3 result should be read in that light.

A fourth limitation is mechanism. We do not take on the question of why the Tobin's Q and ROA responses to the H3 moderation differ, though an event-study approach or long-horizon buy-and-hold abnormal return (BHAR) analysis would be a natural follow-up. Relatedly, while we corroborate the strategy interpretation with firm-level BEV sales shares and the timing of platform launches, the underlying disclosure bases differ across firms (wholesale versus retail, calendar versus fiscal year) and several Japanese OEMs do not publish global BEV unit splits; a richer triangulation—analyst reports, management guidance in investor-relations communications, and plant-level energy data—would strengthen the qualitative side of the identification and is a worthwhile complement to the small-sample regressions reported here. Finally, we do not yet observe the financial impact of CBAM's December 2025 extension proposal, which targets automotive components for 2028 implementation; an ex-post analysis of that step will be informative once the policy is in force.

These limitations notwithstanding, the paper contributes what we think is a useful empirical frame for the Korea–Japan automaker electrification divergence. The single-database collection protocol is reproducible end to end, and the compound-event identification design is portable to other cross-country carbon-finance questions. We hope it will be useful as a template for subsequent work.

Disclaimer. The views expressed in this paper are solely those of the authors and do not necessarily reflect those of their affiliated institutions.

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