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From Wholesale Fuel Shock to Network-and-Tax Wedge: Industrial Electricity Tariff Component Dispersion and Manufacturing Output in Europe

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Abstract

When wholesale natural gas and power markets retreat from an acute supply shock, cross-country industrial electricity cost divergence persists as dispersion rotates from traded generation prices toward regulated grid charges and national fiscal wedges. Applying an exact variance–covariance decomposition across all 27 European Union Member States from 2017 to 2025, with semi-annual tax-wedge tracking through the first half of 2026, we document a structural reconfiguration of non-household tariff dispersion across three audited price definitions. In the benchmark medium-scale industrial consumption band (500 to 1,999 MWh annually), the share of cross-country tariff variance attributable to energy and supply costs fell from 57.26% in 2023 to 33.85% in 2025, whereas the regulated network variance share doubled from 6.54% to 13.03% and the net non-recoverable tax variance share reached 22.55%. Across 25 paired Member States in 2025, medium-consumption facilities faced unit network charges 21.85 EUR/MWh above large electro-intensive users alongside an additional 10.98 EUR/MWh net fiscal differential. Combining predetermined 2017–2019 sectoral electricity and gas intensities with a mutually exclusive panel of eight manufacturing divisions across 20 Member States (N = 1,182, 2017–2025) under country-by-sector, country-by-year, and sector-by-year fixed effects, we find a negative conditional association between electricity intensity interacted with regulated network charges and real manufacturing output (-0.00191; wild cluster bootstrap p = 0.0130; Holm family-wise p = 0.0390 across three electricity components), which strengthens on the strictly post-base-period 2020–2025 panel (-0.00283, bootstrap p = 0.0177, N = 783), under a five-country technological benchmark (-0.00259, bootstrap p = 0.0298), and with sector linear trends (-0.00213, bootstrap p = 0.0348), while attenuated first-difference horizons and a negative extended pre-crisis lead (-0.00588, bootstrap p = 0.0290) highlight bidirectional revenue-cap denominator feedback.

Keywords: industrial electricity tariffs; regulated network charges; fiscal tax wedges; variance decomposition; European manufacturing; energy intensity

1. Introduction

Energy price shocks in integrated industrial markets are conventionally modeled as common or converging wholesale fuel disturbances whose competitive consequences fade as primary commodity markets normalize (Aldy & Pizer, 2015; Ganapati et al., 2020; Moll et al., 2023). Yet industrial establishments purchase delivered electricity under composite retail schedules that bundle three institutionally distinct

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elements: contestable energy and supply procurement, regulated transmission and distribution network charges, and statutory non-recoverable taxes, levies, and fiscal allowances (Borenstein, 2016; Sato et al., 2019; Borenstein & Bushnell, 2022). While cross-border interconnectors and day-ahead market coupling compress wholesale generation spreads once acute fuel disruptions subside (Zachmann, 2008; Newbery et al., 2018; Fabra, 2023), grid capital recovery and national tax-and-subsidy rules remain governed by fragmented domestic regulatory regimes (Richstein & Hosseinioun, 2020; Serrano González & Álvarez Alonso, 2021). Consequently, wholesale fuel disinflation can leave manufacturing establishments exposed to persistent cross-country divergence anchored in non-energy tariff wedges.

This study examines how the cross-country variance–covariance structure of European non-household electricity prices evolved from 2017 through the post-crisis stabilization of 2025 and early 2026, and how individual tariff components covary with real manufacturing production across sectors of differing predetermined electricity dependence. Prior empirical work on industrial energy costs and European manufacturing performance has established that higher aggregate retail electricity prices reduce employment, investment, and establishment-level output in electro-intensive activities (Marin & Vona, 2019; Marin & Vona, 2021; Bijnens et al., 2022; Fontagné et al., 2024), and that international industrial energy price dispersion reflects tax policy more than fuel procurement (Dechezleprêtre & Sato, 2017; Sato et al., 2019). Parallel research in utility regulation demonstrates that volumetric recovery of sunk transmission and distribution costs distorts marginal electrification incentives and generates sharp tariff gradients across consumption tiers (Simshauser, 2016; Passey et al., 2017; Lolli et al., 2021; Savelli & Morstyn, 2021), while retail price regulation alters cross-sectional tariff dispersion (Esplin et al., 2020; Fange, 2022). However, existing cross-country manufacturing panels aggregate delivered electricity tariffs into a single unit price, leaving unquantified both the exact variance–covariance shifts among wholesale supply, regulated grid fees, and fiscal levies after the 2022–2023 European energy shock and their distinct conditional associations with disaggregated manufacturing output.

We advance this literature on three fronts. First, before conducting econometric estimation, we perform a comprehensive statistical accounting audit of official European non-household electricity tariff series across all seven annual consumption bands (from below 20 MWh to 150,000 MWh and above) over 2017–2025, supplemented by semi-annual tax-tier tracking through the first half of 2026 (European Union, 2016; Eurostat, 2023; Eurostat, 2026a). Across 1,594 complete country–band–year cells, we show that combining annual reported energy and network components with semi-annual net non-recoverable tax wedges yields a reconciliation discrepancy against unweighted semi-annual total prices with a mean of −0.53 EUR/MWh and a standard deviation of 6.15 EUR/MWh, reflecting unobserved temporal delivery weights, data revisions, or reporting differences across annual and bi-annual filings (Statistics Denmark, 2025). Furthermore, we demonstrate that statutory allowance items reported as voluntary sub-elements of net taxes carry non-uniform positive and negative signs across Member States, precluding naive cross-country averaging of raw allowance values. By preserving the reconciliation term explicitly and auditing three alternative variance definitions, our framework establishes an accounting-consistent decomposition of cross-country industrial tariff dispersion.

Second, we document a pronounced post-crisis rotation in cross-European industrial electricity price dispersion alongside persistent consumption-band regressivity. In the standard medium-scale industrial demand band (Band IC, 500 to 1,999 MWh per year, $N = 27$ Member States), cross-country variance in energy and supply costs accounted for 57.26% of total delivered price variance at the 2023 retail peak, declining to 33.85% by 2025 as wholesale fuel prices retreated. Over the same two-year interval, the variance share of regulated network charges doubled from 6.54% to 13.03%, the net non-recoverable tax variance share rose from 20.26% to 22.55%, and positive energy–network and energy–tax covariances contributed an additional 29.31%. Identical structural rotations hold under both the annual value-added-tax-excluded component definition and the semi-annual tax-residual definition. Simultaneously, regulated grid cost al-

location exhibits substantial regressivity across annual demand tiers: in 2025, paired comparisons across $n = 25$ Member States show that Band IC consumers paid 21.85 EUR/MWh more in regulated network charges (positive in 23 of 25 countries) and 10.98 EUR/MWh more in net non-recoverable taxes than large electro-intensive consumers in Band IF (70,000 to 149,999 MWh). Semi-annual series extending to the first half of 2026 confirm that emergency fiscal subsidies compressed median net non-recoverable tax wedges to 6.70 EUR/MWh in the second half of 2023 before fiscal clawbacks restored the Band IC median to 17.60 EUR/MWh by the first half of 2026.

Third, adapting the predetermined factor-dependence design of Rajan and Zingales (1998), we match pre-crisis (2017–2019) sectoral electricity and natural gas intensities to a mutually exclusive panel of eight manufacturing divisions with directly published official production indices across 20 European Union countries over 2017–2025 ($N = 1{,}182$ country–sector–year observations across 134 country–sector units), supplemented by strictly post-base-period (2020–2025, $N = 783$) and ten-sector ($N = 1{,}463$) panels (European Commission, 2022; Eurostat, 2019; Eurostat, 2021; Eurostat, 2026b). Absorbing country-by-sector, country-by-year, and sector-by-year fixed effects and conducting small-cluster inference via 9,999 restricted wild cluster bootstrap replications (Cameron et al., 2008; MacKinnon et al., 2023), we estimate a negative conditional association between predetermined electricity intensity interacted with regulated network charges and log real manufacturing output ($\hat{\beta}_N = -0.00191$, country-clustered $p = 0.0486$, wild cluster bootstrap $p = 0.0130$, Holm family-wise $p = 0.0390$ across the three electricity components, inverted bootstrap 95% confidence interval $[-0.00406, -0.00033]$). By contrast, conditional interactions with contemporaneous energy and supply tariffs, net non-recoverable taxes, and industrial natural gas prices are statistically indistinguishable from zero. The negative network-tariff gradient strengthens on the strictly out-of-sample 2020–2025 panel using either domestic intensities ($\hat{\beta}_N = -0.00283$, bootstrap $p = 0.0177$) or a five-country technological benchmark ($\hat{\beta}_N = -0.00259$, bootstrap $p = 0.0298$), and holds when controlling for exposure-by-linear-time trends ($\hat{\beta}_N = -0.00213$, bootstrap $p = 0.0348$) and across all 20 leave-one-country-out subsamples. At the same time, attenuated first-differenced local-projection slopes and a negative extended pre-crisis lead coefficient incorporating 2020 pandemic-year tariffs ($\hat{\beta}_{N,\text{lead}} = -0.00588$, bootstrap $p = 0.0290$) point to bidirectional feedback under revenue-cap grid regulation, motivating disciplined interpretation of the estimates as medium-term conditional associations.

The remainder of the commentary is structured as follows. Section 2 develops the tariff variance–covariance identity, consumption-band pricing schedules, and revenue-cap factor-exposure hypotheses. Section 3 details European regulatory reporting rules, sector harmonization, and the algebraic reconciliation audit. Section 4 sets out the three-way fixed-effects specification and wild cluster bootstrap inference procedures. Section 5 presents the variance decomposition and consumption-band incidence results. Section 6 reports the sectoral manufacturing regressions, dynamic local projections, and sensitivity checks. Section 7 consolidates methodological limitations, and Section 8 discusses implications for European network tariff design and statistical reporting.

2. Analytical Framework and Testable Hypotheses

2.1. Exact Variance–Covariance Decomposition of Delivered Industrial Tariffs

Consider an industrial electricity consumer operating in Member State $c \in \{1, \ldots, C\}$, annual consumption band b, and calendar year t. For value-added-tax-registered manufacturing enterprises, recoverable value-added tax washes out of variable input cost, leaving the net delivered price per unit of electricity determined by three additive components: the contestable energy and retail supply price E_{cbt}, the regulated transmission and distribution network charge N_{cbt}, and the net non-recoverable tax-and-levy wedge T_{cbt} net of statutory allowances and emergency price-cap credits:

$$P^{*}_{cbt} = E_{cbt} + N_{cbt} + T_{cbt}. \quad (1)$$

Within each consumption band b and year t across a balanced cross-section of Member States, the sample cross-country variance of delivered industrial electricity tariffs in Equation (1) decomposes into three direct component variances ($\mathrm{Var}_c(E_{cbt})$, $\mathrm{Var}_c(N_{cbt})$, and $\mathrm{Var}_c(T_{cbt})$) and three symmetric pairwise covariance terms:

$$\mathrm{Var}_c(P^{*}_{cbt}) = \sum_{K \in \{E,N,T\}} \mathrm{Var}_c(K_{cbt}) + 2\mathrm{Cov}_c(E_{cbt}, N_{cbt}) + 2\mathrm{Cov}_c(E_{cbt}, T_{cbt}) + 2\mathrm{Cov}_c(N_{cbt}, T_{cbt}). \quad (2)$$

Dividing each right-hand-side term in Equation (2) by $\mathrm{Var}_c(P^{*}_{cbt})$ yields six additive dispersion shares that sum identically to unity without sign truncation. During an acute fuel supply shock, such as the 2022–2023 curtailment of pipeline gas deliveries to Europe, marginal gas-fired generation sets wholesale clearing prices unevenly across bidding zones with differing generation mixes and forward-contract roll-over speeds, driving $\mathrm{Var}_c(E_{cbt})$ upward (Newbery et al., 2018; Fabra, 2023). Simultaneously, national governments that experience the steepest wholesale spikes enact emergency levy suspensions or direct retail price caps, inducing strongly negative cross-country covariance $2\mathrm{Cov}_c(E_{cbt}, T_{cbt}) < 0$ that partially buffers end-user dispersion.

Once wholesale fuel prices retreat, two institutional mechanisms prevent delivered industrial tariff variance from returning to pre-shock symmetry. First, transmission and distribution system operators operate under revenue-cap or rate-of-return regulation in which thermal congestion redispatch expenses, grid-loss procurement costs incurred at peak prices, and distribution reinforcement capital expenditures for renewable integration are capitalized into regulatory asset bases and recovered with administrative lags over subsequent tariff periods (Borenstein, 2016; Simshauser, 2016; Borenstein & Bushnell, 2022). Second, Member States withdraw emergency fiscal relief at divergent fiscal speeds, while countries with elevated generation costs also face higher monetized grid-loss charges, turning $2\mathrm{Cov}_c(E_{cbt}, N_{cbt})$ and $2\mathrm{Cov}_c(E_{cbt}, T_{cbt})$ positive. This yields our first testable hypothesis:

- **Hypothesis 1 (Post-Shock Dispersion Reconfiguration).** *As European wholesale energy costs recede between 2023 and 2025, the cross-country variance share of contestable energy and supply costs $Var_c(E_{cbt})/Var_c(P^{*}_{cbt})$ declines across industrial consumption bands, whereas the combined dispersion shares of regulated network charges, net non-recoverable fiscal wedges, and positive component covariances expand.*

2.2. Nonlinear Grid Cost Recovery Across Consumption Bands

Network infrastructure involves high fixed capital ratios and low short-run marginal delivery costs (Passey et al., 2017; Savelli & Morstyn, 2021). Under Ramsey-Boiteux pricing principles and industrial competitiveness exemptions, European national regulatory authorities structure non-household network tariffs as declining block or voltage-differentiated schedules. Facilities drawing power at extra-high or high voltage in upper annual consumption bands (such as Band IF, 70,000 to 149,999 MWh) bypass lower-voltage distribution transformation layers and frequently qualify for statutory network-charge rebates granted to trade-exposed electro-intensive users (Richstein & Hosseinioun, 2020; Serrano González & Álvarez Alonso, 2021). Medium-consumption manufacturing plants connected at medium voltage (such as Band IC, 500 to 1,999 MWh) bear both residual distribution cost recovery and unrebated environmental or renewable-support levies (Lolli et al., 2021). As grid capital and redispatch revenue requirements rise after 2022, regulated tariff schedules place a disproportionate unit burden on medium-volume industrial demand bands relative to upper electro-intensive tiers:

- **Hypothesis 2 (Consumption-Band Regressivity of Non-Energy Wedges).** *Unit regulated network charges and net non-recoverable tax wedges decline systematically across annual electricity consumption bands, generating a persistent positive unit cost differential between medium-scale industrial users (Band IC) and large electro-intensive users (Band IF) across European Member States.*

2.3. Predetermined Electricity Intensity, Revenue-Cap Billing, and Sectoral Output Exposure

To link tariff component trajectories to real industrial production, consider a constant-elasticity cost-share representation in which manufacturing sector i in country c combines electricity (with predetermined pre-crisis physical intensity e_{ci}, measured in GWh per million EUR of nominal gross value added), natural gas (with predetermined intensity g_{ci}), labor, and intermediate inputs. Absorbing time-invariant comparative advantage (α_{ci}), country-wide macroeconomic, monetary, and aggregate demand shocks (λ_{ct}), and European-wide sector-specific demand and technology cycles (μ_{it}), differential output adjustments across manufacturing sectors within the same country and year depend on how each tariff component alters persistent unhedged operating costs (Ganapati et al., 2020; Marin & Vona, 2021; Fontagné et al., 2024).

The three electricity tariff components differ fundamentally in contractibility and regulatory determination. Medium and large industrial buyers partially insulate production runs from short-term wholesale supply spikes E_{ct} through multi-year fixed-price supply contracts, corporate power purchase agreements, or intra-group hedging, while emergency fiscal transfers T_{ct} explicitly target high-cost periods to stabilize cash flow. Regulated network charges N_{ct}, by contrast, are location-bound monopoly tariffs determined under an allowed-revenue cap R_{ct}^{cap} divided by billed network load Q_{ct}:

$$N_{ct} = \frac{R_{ct}^{\text{cap}}}{Q_{ct}}. \tag{3}$$

Equation (3) highlights two reinforcing equilibrium channels linking regulated grid tariffs and electricity-intensive manufacturing output. On the cost-incidence side, upward resets in R_{ct}^{cap} driven by transmission expansion and congestion management cannot be hedged in forward commodity markets, imposing a durable local cost wedge that compresses medium-term output among high-e_{ci} divisions. Simultaneously, on the billing-denominator side, macroeconomic or heavy-industrial contractions that depress Q_{ct} (such as the 2020 pandemic shock or structural deindustrialization in power-intensive regions) mechanically raise unit volumetric tariffs N_{ct} unless regulators decouple sunk capital recovery from volumetric throughput. Both channels generate a negative medium-term equilibrium co-movement between $e_{ci}N_{ct}$ and sectoral output levels, even when year-to-year first-differenced adjustments are gradual:

- **Hypothesis 3 (Component-Specific Output Conditional Association).** *Conditional on country-by-sector, country-by-year, and sector-by-year fixed effects as well as predetermined natural gas intensity interacted with industrial gas prices, real manufacturing output in electricity-intensive sectors exhibits a negative medium-term conditional association with regulated network charges, distinct from the attenuated contemporaneous associations of hedged wholesale supply and fiscally buffered net tax components.*

3. Regulatory Reporting Structure, Data Harmonization, and Tariff Identity Audit

3.1. European Price Statistics Regulation and Primary Data Universe

All empirical series and statutory records in this study satisfy an evidence cutoff of 13 November 2026, drawing on completed calendar-year releases through 2025 and semi-annual price releases through the first half of 2026. Under Regulation (EU) 2016/1952 (European Union, 2016), electricity supply undertakings across all 27 European Union Member States report volume-weighted non-household retail electricity prices across seven standardized annual consumption bands: Band IA (below 20 MWh), Band IB (20 to 499 MWh), Band IC (500 to 1,999 MWh), Band ID (2,000 to 19,999 MWh), Band IE (20,000

to 69,999 MWh), Band IF (70,000 to 149,999 MWh), and Band IG (150,000 MWh and above). Each consumption band is defined strictly by annual metered electricity purchases at the reporting point, independent of enterprise headcount or balance-sheet size (Eurostat, 2026a).

We assemble six official Eurostat statistical domains covering all 27 Member States: (i) annual non-household electricity price components (energy and supply, network costs, total taxes and levies, six disaggregated tax sub-categories, and statutory allowances, official update 16 October 2026) across Bands IA–IG for 2017–2025; (ii) semi-annual non-household electricity prices reported across three tax tiers—excluding all taxes and levies, excluding value-added tax and other recoverable taxes, and including all taxes—from the first half of 2017 through the first half of 2026 (official update 19 October 2026); (iii) semi-annual industrial natural gas prices excluding recoverable taxes in mid-scale industrial Band I3 (10,000 to below 100,000 GJ annually, official update 19 October 2026) for 2017–2025; (iv) calendar-adjusted annual (2017–2025) and quarterly (2017Q1–2026Q3) manufacturing production volume indices (2021 = 100, official update 11 November 2026) across two-digit manufacturing divisions and published official aggregates (Eurostat, 2021; Eurostat, 2026b); (v) complete annual physical industrial electricity and natural gas final energy consumption balances in GWh across manufacturing subsectors (official update 27 August 2026) (Eurostat, 2019; European Commission, 2022); and (vi) national accounts industry-level gross value added in current million EUR for 2017–2019 (official update 5 November 2026). An administrative Eurostat database navigation reorganization announced on 17 September 2026 and effective 1 October 2026 altered catalog placement without modifying underlying price definitions or historical values. Because annual electricity cost-component decompositions are published only through 2025 at the evidence cutoff, annual panel regressions span 2017–2025 without extrapolating 2025 component shares into 2026.

3.2. Algebraic Audit of Tariff Identities, Reconciliation Gaps, and Allowance Signs

A rigorous decomposition requires auditing whether Eurostat's annual component tables and semi-annual tax-tier tables satisfy exact accounting identities prior to constructing regression variables. Our cross-table audit establishes three empirical regularities that govern measurement design.

First, pursuant to Annex II of Regulation (EU) 2016/1952, total taxes, fees, levies, and charges in the annual component dataset equal the sum of the six published tax sub-items—value-added tax, renewable energy and cogeneration levies, capacity levies, environmental taxes, nuclear levies, and other taxes and levies—within four-decimal rounding (≤ 0.20 EUR/MWh) across all 1,444 cells reporting every tax sub-item, and disaggregated allowance sub-items sum identically to total allowances across all 439 complete cells. Total taxes and sub-items must therefore never be summed together.

Second, annual component tables report prices including all taxes alongside a price excluding value-added tax only, whereas non-household enterprises recover additional non-VAT deductible energy taxes in several Member States (most prominently in Germany, where the annual VAT-only-excluded price exceeds the semi-annual recoverable-tax-excluded mean by 8.64 EUR/MWh on average). To isolate the net non-recoverable fiscal wedge T_{cbt} defined in Equation (1), we compute for each country–band–year with both semesters observed the arithmetic mean of the two semi-annual differences between prices excluding recoverable taxes and prices excluding all taxes and levies. Combining annual energy (E_{cbt}) and regulated network (N_{cbt}) components with this semi-annual net non-recoverable tax wedge defines the constructed industrial price $P^{*}_{cbt} = E_{cbt} + N_{cbt} + T_{cbt}$. Comparing P^{*}_{cbt} against the unweighted annual mean of reported semi-annual prices excluding recoverable taxes ($\bar{P}_{cbt}$) reveals an explicit annual–semester reconciliation bridge:

$$\Delta_{cbt} = P^{*}_{cbt} - \bar{P}_{cbt} = (E_{cbt} + N_{cbt}) - \bar{X}_{cbt}, \tag{4}$$

where $\bar{X}_{cbt}$ denotes the unweighted mean of the two semi-annual prices excluding all taxes. Across 1,594 complete country–band–year cells over 2017–2025, Δ_{cbt} has a sample mean of −0.53 EUR/MWh (−0.000526 EUR/kWh), a standard deviation of 6.15 EUR/MWh, and a maximum absolute discrepancy of 81.35 EUR/MWh; 1,460 cells lie within ±5.00 EUR/MWh, 1,170 within ±1.00 EUR/MWh, and 518 within ±0.05 EUR/MWh. Discrepancies can reflect temporal delivery weighting across semesters, subsequent statistical revisions, or source-specific reporting differences whose cell-by-cell origin is not identified in public metadata. In particular, Denmark exhibits a persistent all-tax annual-versus-semester discrepancy averaging −99.45 EUR/MWh without carrying a source differing-definition flag in Eurostat metadata (whereas source definition flags appear in Spain, Italy, Cyprus, Romania, and Finland), and national documentation confirms recoverable-tax rules without explaining the annual gap (Statistics Denmark, 2025). Instead of absorbing Δ_{cbt} silently into T_{cbt}, we retain Δ_{cbt} as an explicit diagnostic in Table 1 and verify all variance decompositions and regressions across all three price definitions, reconciliation-tolerance subsamples, and country jackknifes omitting Denmark and flagged jurisdictions.

Third, pursuant to Eurostat's 26 April 2023 subsidy reporting guidance (Eurostat, 2023), statutory allowances and emergency compensation credits are already netted into published tax-tier prices and reported separately only as voluntary memorandum items. Auditing all 1,701 EU27 × 7-band cells over 2017–2025 reveals 447 reported totals (389 exact zeros, 35 positive values, and 23 negative values across Austria, Bulgaria, Greece, and Luxembourg) alongside 1,254 unreported cells. Among the 58 non-zero allowance cells with complete tax sub-items, published net tax totals already reconcile in every case, whereas adding or subtracting the allowance a second time violates rounding bounds in 45 cases. Raw cross-country allowance means therefore have no valid interpretation as harmonized subsidy volumes.

3.3. Mutually Exclusive Sectoral Mapping and Sample Attrition

Matching physical industrial energy balances to manufacturing production volume indices requires strict mutual exclusivity so that aggregate manufacturing is never pooled with its constituent divisions and no energy flow is double-counted. Coke and refined petroleum products belong to the energy transformation sector outside final manufacturing consumption, and repair and installation of machinery lacks a dedicated industrial energy-balance counterpart (Eurostat, 2019); both are excluded from the matched panel. Furthermore, Eurostat energy balances separate iron and steel from non-ferrous metals, whereas public short-term production statistics publish combined basic metals. Summing iron-and-steel and non-ferrous physical energy flows once into basic metals yields eight mutually exclusive manufacturing sectors with directly published official production volume indices: food, beverages, and tobacco; textiles, wearing apparel, and leather; wood and wood products; paper, pulp, and printing; chemicals and pharmaceuticals; non-metallic mineral products; basic metals; and transport equipment.

Two remaining energy-balance categories—fabricated metal products and machinery, and rubber, plastics, furniture, and other manufacturing excluding repair—have no directly published combined short-term production index. Keeping researcher-constructed indices separate from the primary specification, we retain the eight official-index sectors as our audited reference sample and construct fixed 2017–2019 nominal-value-added-weighted indices (rebased to 2017–2019 = 100 before aggregation) for those two categories solely in an explicit ten-sector sensitivity model.

For each country–sector pair (c, i), predetermined electricity intensity e_{ci} and natural gas intensity g_{ci} are computed as the arithmetic mean over 2017, 2018, and 2019 of annual final consumption (in GWh) divided by contemporaneous nominal gross value added (in million EUR), requiring all three pre-crisis years to be observed with strictly positive value added. True reported zero gas consumption is preserved, while confidential or missing cells remain missing without zero-imputation. Starting from the potential grid of 27 × 8 × 9 = 1,944 country–sector–year cells in the primary eight-sector panel, restricting sequentially to observed positive official production indices retains 1,204 observations (740 cells confidential

or unpublished in smaller Member States), requiring complete three-year pre-crisis electricity and gas intensities retains 1,188 observations, and requiring complete two-semester industrial gas control prices retains our final reference sample of $N = 1{,}182$ country–sector–year observations spanning 20 EU Member States (Austria, Belgium, Bulgaria, Czechia, Germany, Denmark, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Lithuania, Latvia, the Netherlands, Poland, Portugal, Romania, and Sweden) and 134 country–sector units (179 unique country–years, as Poland lacks a complete two-semester Band I3 gas price in 2024). Table 1 reports descriptive statistics at each variable's natural unit of variation, including the explicit country–year reconciliation wedge Δ_{ct}.

Table 1. Summary statistics of the matched European manufacturing and tariff component panel (2017–2025).

Variable (unit)	Obs.	Mean	SD	P25	Median	P75	Min	Max	Level
Manufacturing production volume index (2021 = 100)	1,182	99.63	18.29	91.70	99.10	103.50	47.20	288.00	CSY
Log manufacturing production volume (log)	1,182	4.59	0.16	4.52	4.60	4.64	3.85	5.66	CSY
Pre-crisis electricity intensity (e_{ci}, GWh/million EUR)	134	1.00	0.98	0.33	0.69	1.21	0.08	4.85	CS
Pre-crisis natural gas intensity (g_{ci}, GWh/million EUR)	134	0.97	1.16	0.20	0.46	1.39	0.00	7.31	CS
Energy and supply component (E_{ct}, Band IC, EUR/MWh)	179	88.45	52.01	47.90	69.10	118.10	30.40	329.20	CY
Regulated network component (N_{ct}, Band IC, EUR/MWh)	179	31.80	12.68	23.90	27.70	37.00	12.00	80.60	CY
Net non-recoverable tax wedge (T_{ct}, Band IC, EUR/MWh)	179	18.01	24.69	3.95	16.15	29.05	-116.15	93.25	CY
Industrial natural gas price (G_{ct}, Band I3, EUR/MWh)	179	51.42	26.70	30.13	44.50	66.65	20.80	159.25	CY
Band IC annual–semester reconciliation wedge (Δ_{ct}, EUR/MWh)	179	-0.53	4.58	-0.40	-0.05	0.10	-32.85	28.40	CY

Notes. Tariff components, natural gas prices, and the reconciliation wedge Δ_{ct} defined in Equation (4) are scaled to EUR/MWh (×1,000) to match Equation (5). Summary moments are computed at each variable's non-redundant observation level across the 20 Member States and eight official-output manufacturing sectors in the reference sample. Negative minimum net non-recoverable tax wedges reflect emergency wholesale price-cap credits exceeding statutory levies during 2022–2023.

4. Empirical Specification and Small-Cluster Inference

To estimate the conditional association between tariff components and sectoral manufacturing output while absorbing arbitrary country-wide macroeconomic shocks and European-wide industry cycles, we estimate the three-way fixed-effects specification:

$$\log Y_{cit} = \alpha_{ci} + \lambda_{ct} + \mu_{it} + \beta_E(e_{ci}E_{ct}) + \beta_N(e_{ci}N_{ct}) + \beta_T(e_{ci}T_{ct}) + \gamma(g_{ci}G_{ct}) + u_{cit}, \tag{5}$$

where Y_{cit} is the calendar-adjusted real production volume index of sector i in Member State c and year t; α_{ci}, λ_{ct}, and μ_{it} denote country-by-sector, country-by-year, and sector-by-year fixed effects; E_{ct}, N_{ct}, and T_{ct} are Band IC industrial electricity tariff components in EUR/MWh; G_{ct} is the Band I3 industrial natural gas price excluding recoverable taxes in EUR/MWh; and e_{ci} and g_{ci} are predetermined 2017–2019 physical electricity and gas intensities in GWh per million EUR of nominal gross value added. Because

physical gas balances follow net calorific value conventions while semi-annual gas price statistics follow gross calorific value conventions, $g_{ci}G_{ct}$ enters as a consistent physical-to-price exposure control without claiming an exact accounting expenditure share. Fixed effects are absorbed via rank-revealing QR decomposition; in the $N = 1{,}182$ reference specification, the absorbed fixed-effect subspace has exact rank 349, full design rank is $r = 353$, and residual degrees of freedom equal 829.

Because tariff components vary at the country–year level and residuals correlate serially and across sectors within Member States, asymptotic cluster-robust standard errors with $G = 20$ country clusters risk finite-sample size distortion (Cameron et al., 2008). Following MacKinnon et al. (2023), we report conventional country-clustered standard errors evaluated against the $t(G-1) = t(19)$ distribution—incorporating the exact full-design finite-sample variance adjustment factor $[G/(G-1)][(N-1)/(N-r)] = 1.500$, corresponding to a standard-error multiplier of $\sqrt{1.500} = 1.225$—alongside two-sided p-values and 95% confidence intervals from 9,999 null-imposed restricted wild cluster bootstrap-t replications using country-level Rademacher weights. All three fixed-effect dimensions and cluster-robust studentized statistics are refitted across every bootstrap draw, 95% confidence intervals are formed by numerical test inversion across a grid of candidate parameter values, and Holm step-down family-wise p-values are computed across the three electricity tariff interactions ($M = 3$) and all four energy exposure terms ($M = 4$).

Because predetermined intensities e_{ci} and g_{ci} are measured over 2017–2019, pooling 2017–2019 observations inside the 2017–2025 estimation window could induce mechanical base-period overlap via nominal value-added denominators, while secular European decarbonization could generate differential linear industry trends correlated with initial energy dependence. We therefore complement Equation (5) with strictly post-base-period (2020–2025) estimations using both domestic intensities (e_{ci}, g_{ci}) and five-country benchmark intensities ($\bar{e}_i, \bar{g}_i$ averaged across Germany, France, Italy, Spain, and the Netherlands), as well as full-sample specifications augmented with exposure-specific linear time trends ($e_{ci}\times t$ and $g_{ci}\times t$).

To trace short-to-medium-run dynamic adjustment paths and inspect pre-existing output growth prior to annual tariff changes, we also estimate conditional local-projection regressions across horizons $h \in \{-2, -1, 0, 1, 2, 3\}$:

$$\Delta_h \log Y_{cit} = \alpha_{ci,h} + \lambda_{ct,h} + \mu_{it,h} + \sum_{k\in\{E,N,T\}} \theta_{k,h}\, e_{ci}\Delta K_{ct} + \delta_h\, g_{ci}\Delta G_{ct} + \varepsilon_{cit,h}, \tag{6}$$

where $\Delta_h \log Y_{cit} = \log Y_{c,i,t+h} - \log Y_{c,i,t-1}$ for non-negative horizons $h \geq 0$ and prior one-year output growth for pre-change diagnostic horizons $h \in \{-2, -1\}$, and $\Delta K_{ct} = K_{ct} - K_{c,t-1}$ denotes annual component changes. Absent an external instrument for regulatory revenue-cap resets, Equations (5) and (6) recover conditional partial associations.

5. Tariff Dispersion Reconfiguration and Consumption-Band Regressivity

5.1. Post-Crisis Variance–Covariance Reconfiguration Across EU27

Figure 1 and Table 2 test Hypothesis 1 by tracking the exact six-term cross-country variance decomposition of delivered industrial electricity prices across consumption bands IC, IE, and IF from 2017 to 2025, together with cross-definition sensitivity checks in Band IC. Prior to the 2021–2022 energy crisis, cross-country delivered price dispersion in Band IC was modest—with a cross-country standard deviation of 26.40 EUR/MWh in 2019 (total variance 0.000697 $\text{EUR}^2/\text{kWh}^2$)—and divided between energy-and-supply variance (54.41%) and net non-recoverable tax variance (48.44%), partially offset by negative energy–network (−11.85%) and energy–tax (−7.26%) covariances.

When Russian pipeline gas curtailments drove wholesale power markets to historic highs in 2022, Band IC total cross-country variance quadrupled to 0.002887 $\text{EUR}^2/\text{kWh}^2$ (standard deviation 53.73 EUR/MWh). Pure energy-and-supply variance reached 130.56% of total delivered variance in 2022, while emergency national tax cuts and retail price subsidies in the hardest-hit Member States generated a large

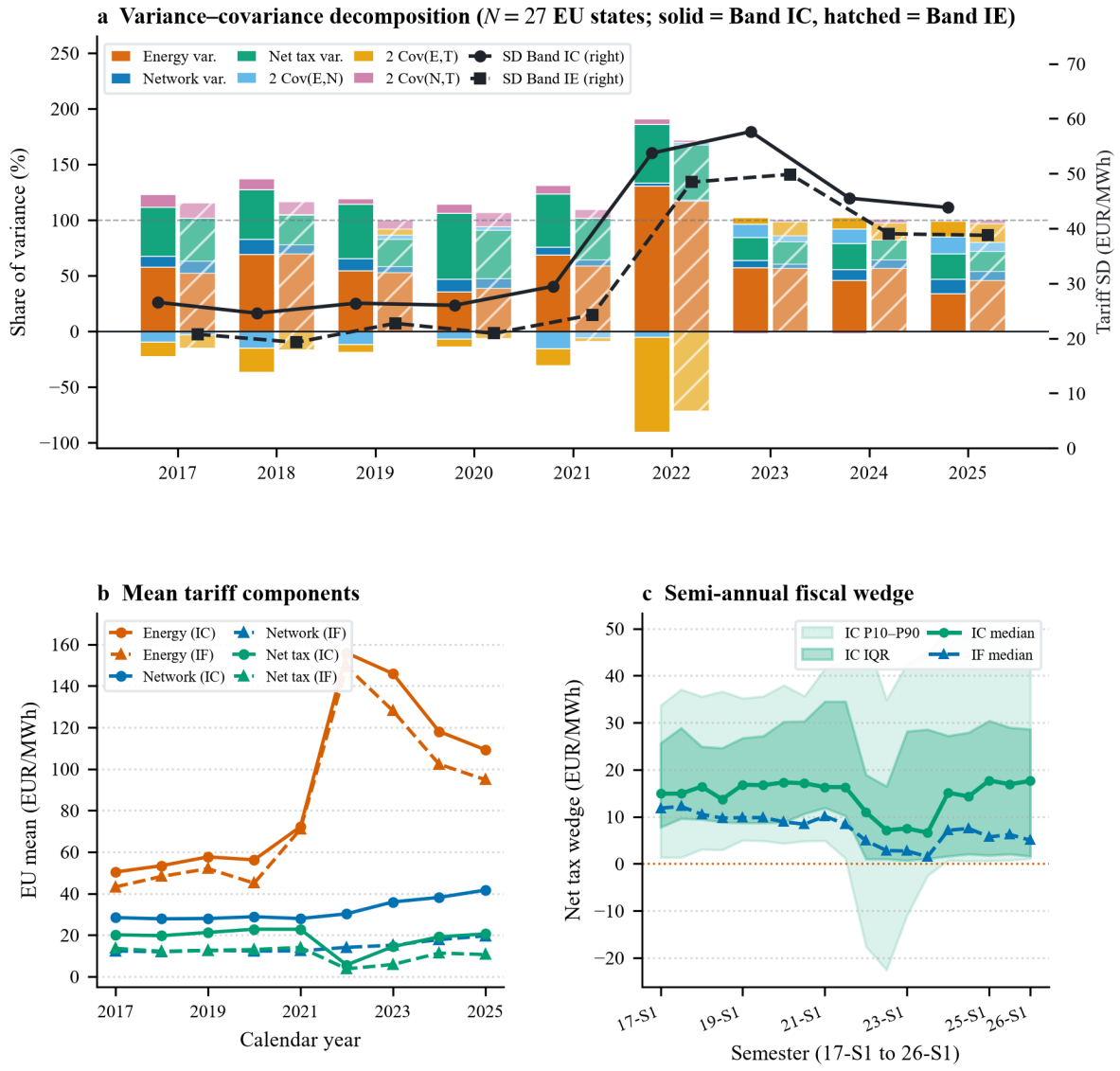


Figure 1. Cross-country variance–covariance decomposition and component trajectories of European industrial electricity tariffs (2017–2026).

Notes. Panel a decomposes cross-country delivered non-recoverable-tax electricity price variance (N = 27 EU Member States per band-year) into six exact variance and covariance shares in Band IC (500–1,999 MWh, solid bars) and Band IE (20,000–69,999 MWh, hatched bars), overlaid with cross-country standard deviations in EUR/MWh on the right axis. Panel b plots unweighted EU mean component trajectories in Bands IC and IF across calendar years 2017–2025. Panel c tracks the cross-country median, interquartile range, and 10th–90th percentile band of semi-annual net non-recoverable tax wedges from 2017-S1 through 2026-S1.

stabilizing negative energy–tax covariance share of −85.11% (Figure 1, Panel a). In 2023, as long-term industrial supply contracts repriced upward and initial emergency subsidies expired unevenly, Band IC cross-country standard deviation peaked at 57.65 EUR/MWh (N = 27), with energy and supply accounting for 57.26% of total variance, net non-recoverable taxes 20.26%, regulated network charges 6.54%, and positive energy–network covariance 11.86%.

Between 2023 and 2025, unweighted EU27 mean Band IC energy and supply prices fell by 25.1% from 145.91 to 109.22 EUR/MWh (Figure 1, Panel b), yet cross-country delivered tariff standard deviation remained elevated at 43.82 EUR/MWh—66.0% above its 2019 pre-crisis level. Consistent with Hypothesis 1, Table 2 demonstrates a pronounced structural rotation in the sources of cross-European price

divergence. In Band IC under our constructed non-recoverable-tax benchmark, the energy-and-supply variance contribution fell by nearly two-thirds in absolute level (from 1,902.81 to 649.84 EUR^2/MWh^2), reducing its share of cross-country tariff variance from 57.26% in 2023 to 33.85% in 2025. Simultaneously, regulated network variance rose both in absolute terms (from 217.43 to 250.20 EUR^2/MWh^2, as unweighted EU27 mean Band IC network charges climbed from 35.92 to 41.61 EUR/MWh) and in relative share, doubling from 6.54% to 13.03%. Net non-recoverable tax variance accounted for 22.55% of 2025 variance, while positive cross-country covariances between energy and network charges (15.35%) and between energy and net taxes (13.96%) contributed 29.31% of delivered dispersion.

The bottom four rows of Table 2 confirm that this post-crisis variance rotation is invariant to how the annual–semester accounting bridge is treated: under the official annual VAT-only-excluded component price ($N = 27$), the Band IC energy variance share drops from 56.66% to 32.99% while the network share doubles from 6.47% to 12.70% and the tax share rises from 19.99% to 23.72%; under the reported semester-mean price absorbing Δ_{ct} into the tax residual ($N = 27$), the energy share drops from 57.88% to 33.45% while the network share rises from 6.61% to 12.88% and the tax-residual share reaches 24.03%. Parallel reconfigurations hold in upper industrial bands: between 2023 and 2025, the regulated network variance share more than doubled in Band IE ($N = 27$) from 3.60% to 8.22% and more than quadrupled in Band IF ($N = 24$ in 2023; $N = 25$ in 2025, confirmed on the balanced 24-country intersection) from 3.12% to 14.04%. Semi-annual tracking through the first half of 2026 (Figure 1, Panel c) shows that fiscal clawbacks restored the Band IC median net tax wedge from its 2023-S2 trough of 6.70 EUR/MWh back to 17.60 EUR/MWh in 2026-S1, with interquartile spreads widening to 26.85 EUR/MWh across Member States.

Table 2. Exact cross-country variance–covariance decomposition of industrial electricity tariffs across demand bands and price definitions (2023 vs. 2025).

Price definition, band, and year	N	SD	Energy (%)	Network (%)	Tax (%)	$2\mathrm{Cov}(E,N)$	$2\mathrm{Cov}(E,T)$	$2\mathrm{Cov}(N,T)$
Constructed non-recov. price, Band IC (2023)	27	57.65	57.26	6.54	20.26	11.86	6.49	-2.42
Constructed non-recov. price, Band IC (2025)	27	43.82	33.85	13.03	22.55	15.35	13.96	1.26
Constructed non-recov. price, Band IE (2023)	27	49.86	56.62	3.60	19.96	5.48	12.53	1.81
Constructed non-recov. price, Band IE (2025)	27	38.76	45.45	8.22	18.31	8.03	16.78	3.22
Constructed non-recov. price, Band IF (2023)	24	58.14	70.65	3.12	9.70	10.75	4.28	1.50
Constructed non-recov. price, Band IF (2025)	25	34.25	61.13	14.04	14.97	-1.54	10.06	1.34
Annual VAT-excluded price, Band IC (2023)	27	57.95	56.66	6.47	19.99	11.74	6.79	-1.66
Annual VAT-excluded price, Band IC (2025)	27	44.38	32.99	12.70	23.72	14.96	14.70	0.93
Semester-mean bridge-in-tax, Band IC (2023)	27	57.34	57.88	6.61	20.54	11.99	5.38	-2.40
Semester-mean bridge-in-tax, Band IC (2025)	27	44.08	33.45	12.88	24.03	15.17	14.27	0.20

Notes. Decompositions apply Equation (2) using unweighted sample variances and covariances across all Member States with complete observations in each band and year. Shares across the six right-hand columns sum to 100.00% within rounding. Total SD equals $\sqrt{\mathrm{Var}_c(P)} \times 1{,}000$ in EUR/MWh. Restricting Band IF in 2025 to the identical 24 Member States observed in 2023 yields nearly identical shares.

5.2. Consumption-Band Regressivity and Statutory Allowance Diagnostics

Figure 2 evaluates Hypothesis 2 across all seven consumption tiers from Band IA (< 20 MWh) to Band IG (≥ 150,000 MWh). Across pre-crisis (2019), peak-crisis (2023), and post-shock (2025) schedules, regulated network charges exhibit a steep downward slope with respect to annual consumption volume, shifting upward across lower and medium bands between 2019 and 2025 (Figure 2, Panel a). In 2025, the cross-country median regulated network charge stood at 84.30 EUR/MWh in Band IA, 54.30 EUR/MWh in Band IB, and 41.50 EUR/MWh in Band IC ($N = 27$), compared with 31.60 EUR/MWh in Band ID ($N = 27$), 20.90 EUR/MWh in Band IE ($N = 27$), 19.60 EUR/MWh in Band IF ($N = 25$), and 9.50 EUR/MWh in Band IG ($N = 21$). The inset empirical cumulative distribution function in Figure 2 (Panel a) illustrates first-order stochastic dominance between the unpaired 2025 Band IC ($N = 27$) and Band IF ($N = 25$) network charge distributions alongside the paired 25-state differential.

Paired within-country comparisons across the $n = 25$ Member States reporting both Band IC and Band IF in 2025 (Figure 2, Panel b) confirm that medium-consumption industrial users paid a mean unit network surcharge of 21.85 EUR/MWh (median 20.90 EUR/MWh) over large electro-intensive facilities, widening from 19.72 EUR/MWh in 2023. The paired network gap is strictly positive in 23 of 25 Member States (exceeding 35 EUR/MWh in Ireland, Germany, Hungary, Belgium, and the Netherlands), zero in Malta, and negative solely in Czechia (−3.90 EUR/MWh). Medium-scale consumers simultaneously faced an average net non-recoverable tax surcharge of 10.98 EUR/MWh (median 7.25 EUR/MWh) relative to Band IF in 2025, up from 8.60 EUR/MWh across 24 paired states in 2023, reflecting industrial carbon-leakage and renewable-surcharge exemptions concentrated in upper voltage and demand tiers (in particular in Italy, Cyprus, the Netherlands, Germany, and Belgium). Finally, Figure 2 (Panel c) documents why raw statutory allowance lines cannot be pooled across borders: from 2017 through 2023 over 85% of EU27 × 7-band cells left the voluntary allowance item unreported (with 3 to 4 positive cells and 0 negative cells per year), and following expanded reporting in 2024–2025 both negative-signed cells (9 in 2024; 14 in 2025) and positive-signed cells (6 in 2024; 4 in 2025) coexist alongside zero entries, validating our reliance on semi-annual tax-tier differences to measure fiscal incidence consistently.

6. Sectoral Manufacturing Output Conditional Associations and Robustness

6.1. Three-Way Fixed-Effects Reference Estimates and Post-2022 Regime Tests

Table 3 presents our reference three-way fixed-effects estimates of Equation (5) across the $N = 1{,}182$ country–sector–year observations (20 Member States, eight disjoint official-output manufacturing sectors, 134 country–sector units, 2017–2025). In Column (1), which includes all four predetermined factor-intensity interactions simultaneously alongside country-by-sector, country-by-year, and sector-by-year fixed effects ($R^2 = 0.7275$, within-$R^2 = 0.0220$), the interaction between pre-crisis electricity intensity and regulated network charges ($e_{ci}N_{ct}$) enters with a coefficient of −0.00191 (country-clustered SE = 0.00090, asymptotic $t(19)$ two-sided $p = 0.0486$, conventional 95% confidence interval $[-0.00380, -0.00001]$). Small-cluster inference via 9,999 restricted wild cluster bootstrap replications yields $p = 0.0130$ and a bounded inverted 95% confidence interval of $[-0.00406, -0.00033]$. Accounting for multiple hypothesis testing across simultaneous tariff interactions via the Holm step-down procedure, the regulated network association remains statistically significant at $p_{\text{Holm}} = 0.0390$ across the three electricity tariff components ($M = 3$) and sits at the 5% boundary ($p_{\text{Holm}} = 0.0520$) across all four electricity and gas exposure terms ($M = 4$).

To gauge economic magnitude within the sample's observed variation, consider two manufacturing sectors within the same Member State whose predetermined electricity intensities differ by 0.88 GWh per million EUR of gross value added—the interquartile spread between the 25th percentile (0.33 GWh/million EUR, typical of transport equipment and apparel) and the 75th percentile (1.21 GWh/million EUR,

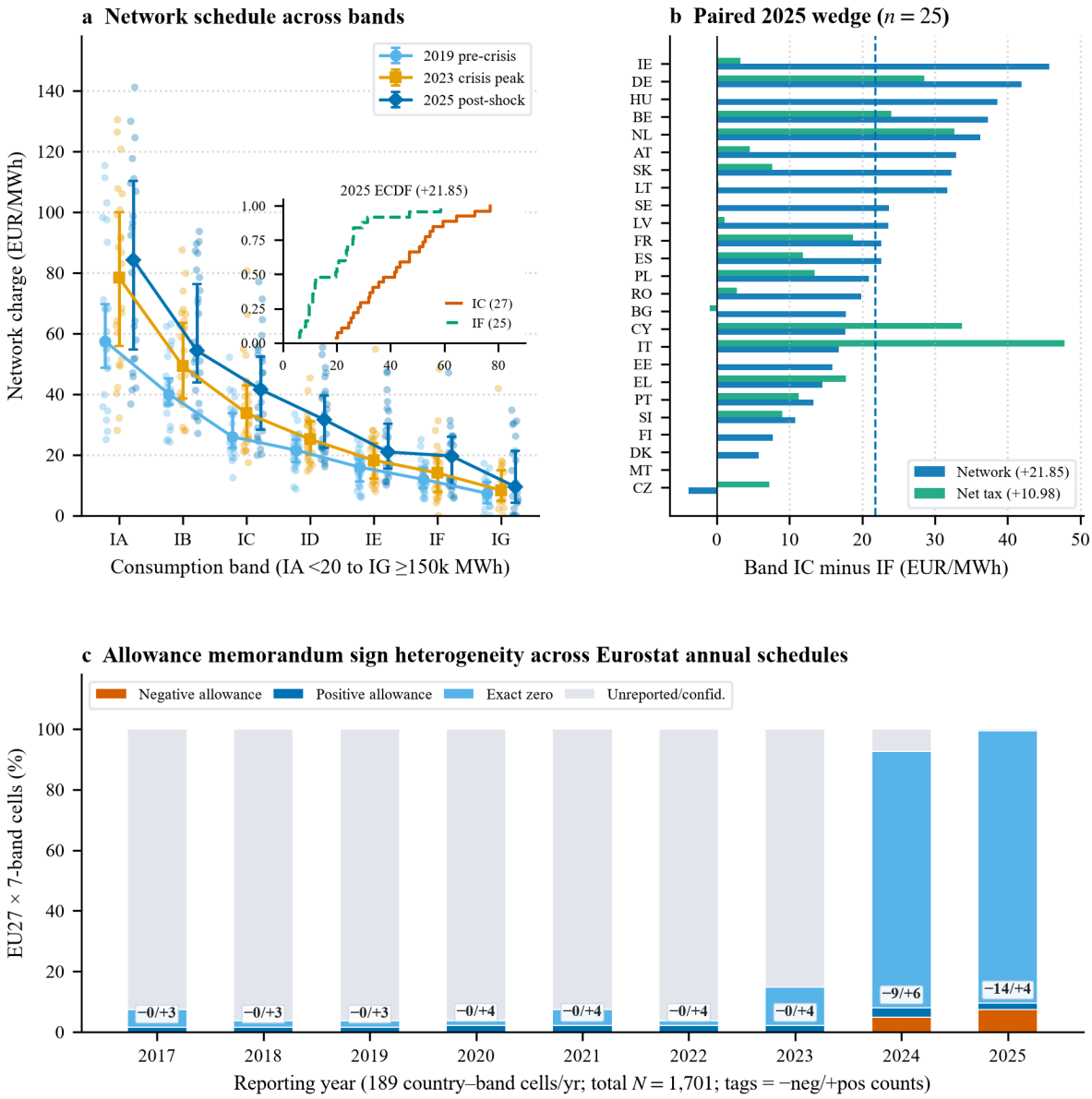


Figure 2. Consumption-band regressivity of regulated network charges, paired non-energy wedges, and allowance sign diagnostics.

Notes. Panel a plots cross-country medians, interquartile ranges, and jittered Member State observations of regulated network charges across annual demand bands IA–IG in 2019, 2023, and 2025, with an inset empirical cumulative distribution function comparing 2025 Band IC (N = 27) and Band IF (N = 25) and reporting the paired 25-state mean gap (+21.85 EUR/MWh). Panel b displays paired 2025 Member State differentials (Band IC minus Band IF, n = 25 states) for regulated network charges and net non-recoverable tax wedges. Panel c classifies all 1,701 EU27 × 7-band cells over 2017–2025 by statutory allowance reporting status and algebraic sign, with callouts reporting exact negative and positive non-zero cell counts each year.

characteristic of chemicals, paper, and non-metallic minerals; see Table 1). In a country–year where Band IC regulated network charges are higher by one cross-country standard deviation (12.68 EUR/MWh), the Column (1) estimate implies a conditional real output differential of $0.88 \times 12.68 \times (-0.001905) = -0.0213$ log points, or −2.10% relative to the lower-intensity sector. Across a comparison involving basic metals or pulp and paper (1.00 GWh/million EUR intensity gap) facing a 20 EUR/MWh network differential, the implied conditional output gap equals −3.74%.

Table 3. Three-way fixed-effects estimates of industrial tariff components and real manufacturing output (2017–2025).

Interaction regressor	(1) Baseline	(2) No-gas	(3) Max-N	(4) Post-2022
Electricity intensity × Energy & supply (E_{ct})	-0.00022	-0.00021	-0.00021	-0.00020
	(0.00028)	(0.00024)	(0.00024)	(0.00025)
	[0.4348/0.4642]	[0.3897/0.3963]	[0.3956/0.4030]	[0.4229/0.4180]
Electricity intensity × Regulated network (N_{ct})	-0.00191	-0.00190	-0.00189	-0.00297
	(0.00090)	(0.00089)	(0.00089)	(0.00154)
	[0.0486/0.0130]	[0.0474/0.0136]	[0.0471/0.0139]	[0.0696/0.0260]
Electricity intensity × Net tax wedge (T_{ct})	-0.00028	-0.00027	-0.00027	-0.00016
	(0.00032)	(0.00028)	(0.00028)	(0.00036)
	[0.3858/0.3334]	[0.3461/0.2899]	[0.3553/0.2909]	[0.6659/0.6346]
Gas intensity × Industrial gas price (G_{ct})	0.00003			0.00003
	(0.00030)			(0.00031)
	[0.9211/0.9041]			[0.9310/0.9206]
Electricity intensity × Energy × $\mathbb{I}(t > 2022)$				-0.00017
				(0.00019)
				[0.3696/0.3249]
Electricity intensity × Network × $\mathbb{I}(t > 2022)$				0.00158
				(0.00110)
				[0.1664/0.1017]
Electricity intensity × Net tax × $\mathbb{I}(t > 2022)$				-0.00028
				(0.00048)
				[0.5582/0.5173]
Observations (N)	1,182	1,182	1,188	1,182
Country–sector units / Country clusters (G)	134/20	134/20	134/20	134/20
Total R^2 / Within R^2	0.7275/0.0220	0.7275/0.0220	0.7286/0.0225	0.7297/0.0296

Notes. Dependent variable is natural log of calendar-adjusted real manufacturing production ($2021 = 100$). Column (1) includes all four Band IC electricity and Band I3 gas interactions; Column (2) omits the gas control on the same $N = 1{,}182$ sample; Column (3) omits gas on the maximum $N = 1{,}188$ sample; Column (4) interacts electricity components with $\mathbb{I}(t > 2022)$. All models absorb country-by-sector, country-by-year, and sector-by-year fixed effects. Tariff components are measured in EUR/MWh and predetermined 2017–2019 intensities in GWh per million EUR nominal GVA. Parentheses report finite-sample-adjusted country-clustered standard errors; square brackets report [cluster p/WCB p] from 9,999 restricted wild cluster bootstrap replications (in Column 1, gas WCB $p = 0.9041$). In Column (1), Holm step-down bootstrap family-wise p-values for regulated network charges equal 0.0390 ($M = 3$ electricity components) and 0.0520 ($M = 4$ including gas).

Consistent with Hypothesis 3, the remaining three contemporaneous cost interactions in Column (1) of Table 3 are small and statistically indistinguishable from zero: electricity intensity interacted with energy and supply costs yields $\hat{\beta}_E = -0.00022$ (bootstrap $p = 0.4642$, bootstrap 95%

CI $[-0.00077, 0.00041]$), electricity intensity interacted with net non-recoverable taxes yields $\hat{\beta}_T = -0.00028$ (bootstrap $p = 0.3334$, bootstrap 95% CI $[-0.00091, 0.00040]$), and natural gas intensity interacted with industrial gas prices yields $\hat{\gamma} = 0.00003$ (bootstrap $p = 0.9041$). Dropping the natural gas control on the identical 1,182-observation sample (Column 2) or expanding to the maximum available 1,188 observations where semi-annual gas prices are incomplete (Column 3) leaves the network interaction virtually unchanged at −0.00190 (bootstrap $p = 0.0136$) and −0.00189 (bootstrap $p = 0.0139$). Absorbed sector-by-year fixed effects (μ_{it}) soak up the common European wholesale gas and power surge affecting energy-intensive industries continent-wide during 2022–2023 (Moll et al., 2023), isolating within-sector cross-country component differentials. Column (4) tests whether component slopes shifted after 2022 by interacting all three electricity exposure terms with a post-2022 indicator $\mathbb{I}(t > 2022)$. The 2017–2022 network slope is −0.00297 (bootstrap $p = 0.0260$), whereas none of the three post-2022 slope-change interactions is statistically significant at the 5% level (network slope difference +0.00158, SE = 0.00110, bootstrap $p = 0.1017$). Although finite cluster count limits power to rule out moderate post-2022 slope attenuation, the post-crisis quantitative weight of regulated grid charges is driven by their rising level and cross-country variance share documented in Section 5 without requiring an increase in marginal slope sensitivity.

6.2. *Post-Base-Period Panels, Secular Trend Controls, Dynamic Horizons, and Measurement Audits*

Figure 3 and Table 4 examine strictly post-base-period (2020–2025) subsamples, exposure-specific linear trend controls, dynamic local-projection horizons, alternative consumption-band and accounting definitions, leave-one-country-out jackknife stability, and pre-trend lead falsification tests.

In the first-differenced local-projection estimates of Equation (6) (Figure 3, Panel a), contemporaneous energy-and-supply changes exhibit a modest negative short-run association at $h = 0$ ($\hat{\theta}_{E,0} = -0.00031$, bootstrap $p = 0.0304$, $N_0 = 1{,}040$) and $h = 1$ ($\hat{\theta}_{E,1} = -0.00024$, bootstrap $p = 0.0452$, $N_1 = 912$) that dissipates at $h = 2$ (−0.00024, bootstrap $p = 0.2349$) and $h = 3$ (−0.00045, bootstrap $p = 0.1845$, $N_3 = 653$). By contrast, annual first differences in regulated network charges yield negative point estimates at $h = 0$ ($\hat{\theta}_{N,0} = -0.00097$, bootstrap $p = 0.0808$) and $h = 2$ ($\hat{\theta}_{N,2} = -0.00086$, bootstrap $p = 0.1777$) and near-zero estimates at $h = 1$ (−0.00012, bootstrap $p = 0.8541$) and $h = 3$ (+0.00002, bootstrap $p = 0.9923$). At pre-change horizon $h = -1$ ($N_{-1} = 912$), prior one-year output growth is statistically unrelated to subsequent network changes ($\hat{\theta}_{N,-1} = -0.00216$, bootstrap $p = 0.1971$) and energy changes ($\hat{\theta}_{E,-1} = 0.00025$, bootstrap $p = 0.0802$), though positively associated with subsequent net tax wedge changes ($\hat{\theta}_{T,-1} = 0.00043$, bootstrap $p = 0.0220$), consistent with governments withdrawing temporary tax relief more rapidly after industrial rebounds. Viewed through Equation (3), short-run annual supply price jumps trigger transitory output dips, whereas the three-way fixed-effects level specification in Table 3 captures lower-frequency persistent sorting of electro-intensive output across jurisdictions with diverging regulated network schedules alongside multi-year revenue-cap feedback.

Table 4. Post-base-period, trend-augmented, accounting-audit, consumption-band, and pre-trend falsification diagnostics.

Specification / diagnostic check	N	G	$\hat{\beta}_N$	Cluster SE	Cluster p	WCB p	WCB CI
Post-base 2020–2025 (domestic intensities e_{ci}, g_{ci})	783	20	-0.00283	0.00125	0.0356	0.0177	[-0.00517, -0.00062]
Post-base 2020–2025 (5-country benchmark $\bar{e}_i, \bar{g}_i$)	783	20	-0.00259	0.00114	0.0346	0.0298	[-0.00565, -0.00038]

(continued)

Table 4 (continued)

Specification / diagnostic check	N	G	$\hat{\beta}_N$	Cluster SE	Cluster p	WCB p	WCB CI
Linear sector trends ($e_{ci} \times t$ and $g_{ci} \times t$, 2017–2025)	1,182	20	-0.00213	0.00109	0.0666	0.0348	[-0.00471, -0.00012]
Linear sector trends + 5-country benchmark (2017–2025)	1,182	20	-0.00286	0.00119	0.0268	0.0293	[-0.00556, -0.00033]
Common 5-country electricity intensity (2017–2025)	1,182	20	-0.00289	0.00117	0.0234	0.0247	[-0.00552, -0.00044]
Alternative tariff band ID (2,000–19,999 MWh)	1,182	20	-0.00277	0.00112	0.0233	0.0192	[-0.00489, -0.00053]
Alternative tariff band IE (20,000–69,999 MWh)	1,182	20	-0.00262	0.00131	0.0590	0.0430	[-0.00523, -0.00010]
Reconciliation gap $\lvert\Delta_{ct}\rvert \leq 5$ EUR/MWh	1,083	20	-0.00236	0.00095	0.0222	0.0144	[-0.00438, -0.00055]
Reconciliation gap $\lvert\Delta_{ct}\rvert \leq 1$ EUR/MWh	859	20	-0.00353	0.00157	0.0370	0.0062	[-0.00726, -0.00085]
Exclude source definition-difference flags	1,140	20	-0.00199	0.00105	0.0737	0.0312	[-0.00433, -0.00016]
Absorb bridge Δ_{ct} into tax residual	1,182	20	-0.00199	0.00090	0.0390	0.0072	[-0.00423, -0.00047]
Annual VAT-only-excluded tax component	1,166	20	-0.00201	0.00094	0.0463	0.0118	[-0.00424, -0.00037]
Balanced nine-year country–sector panel	1,089	19	-0.00206	0.00094	0.0414	0.0070	[-0.00434, -0.00044]
Ten-sector panel incl. constructed GVA indices	1,463	20	-0.00215	0.00088	0.0238	0.0058	[-0.00417, -0.00049]
Full-sample 1-year-ahead lead falsification	1,054	20	-0.00186	0.00128	0.1616	0.0954	[-0.00537, 0.00026]
Strict pre-crisis lead test (2017–2018 output)	266	20	-0.00666	0.00695	0.3499	0.1979	[-0.02350, 0.00337]
Extended pre-crisis lead test (incl. 2020 tariffs)	399	20	-0.00588	0.00404	0.1621	0.0290	[-0.01691, -0.00050]

Notes. Each row re-estimates Equation (5) under the stated sample window, intensity anchor, trend control, tariff band, or accounting modification, retaining country-by-sector, country-by-year, and sector-by-year fixed effects and gas controls. Five-country benchmark rows use unweighted 2017–2019 mean intensities across Germany, France, Italy, Spain, and the Netherlands. In the bottom three rows, the reported coefficient is the one-year-ahead network tariff lead ($e_{ci}N_{c,t+1}$) estimated jointly with contemporaneous tariffs; in the full-sample lead row, contemporaneous network tariffs enter at $\hat{\beta}_N = -0.00105$ (SE = 0.00071, bootstrap $p = 0.0674$, WCB 95% CI $[-0.00292, 0.00005]$). WCB CIs are inverted from 9,999 restricted wild cluster bootstrap replications.

Table 4 and Figure 3 (Panels b and c) establish five sets of empirical diagnostics:

1. **Strictly post-base-period (2020–2025) and common technological intensity tests.** Eliminating all 2017–2019 base-period years so that predetermined intensities precede every outcome observation ($N = 783$, $G = 20$) strengthens the regulated network coefficient to -0.00283 (SE = 0.00125, cluster $p = 0.0356$, bootstrap $p = 0.0177$, WCB 95% CI $[-0.00517, -0.00062]$). Replacing domestic intensities on this strictly out-of-sample 2020–2025 window with five-country technological bench-

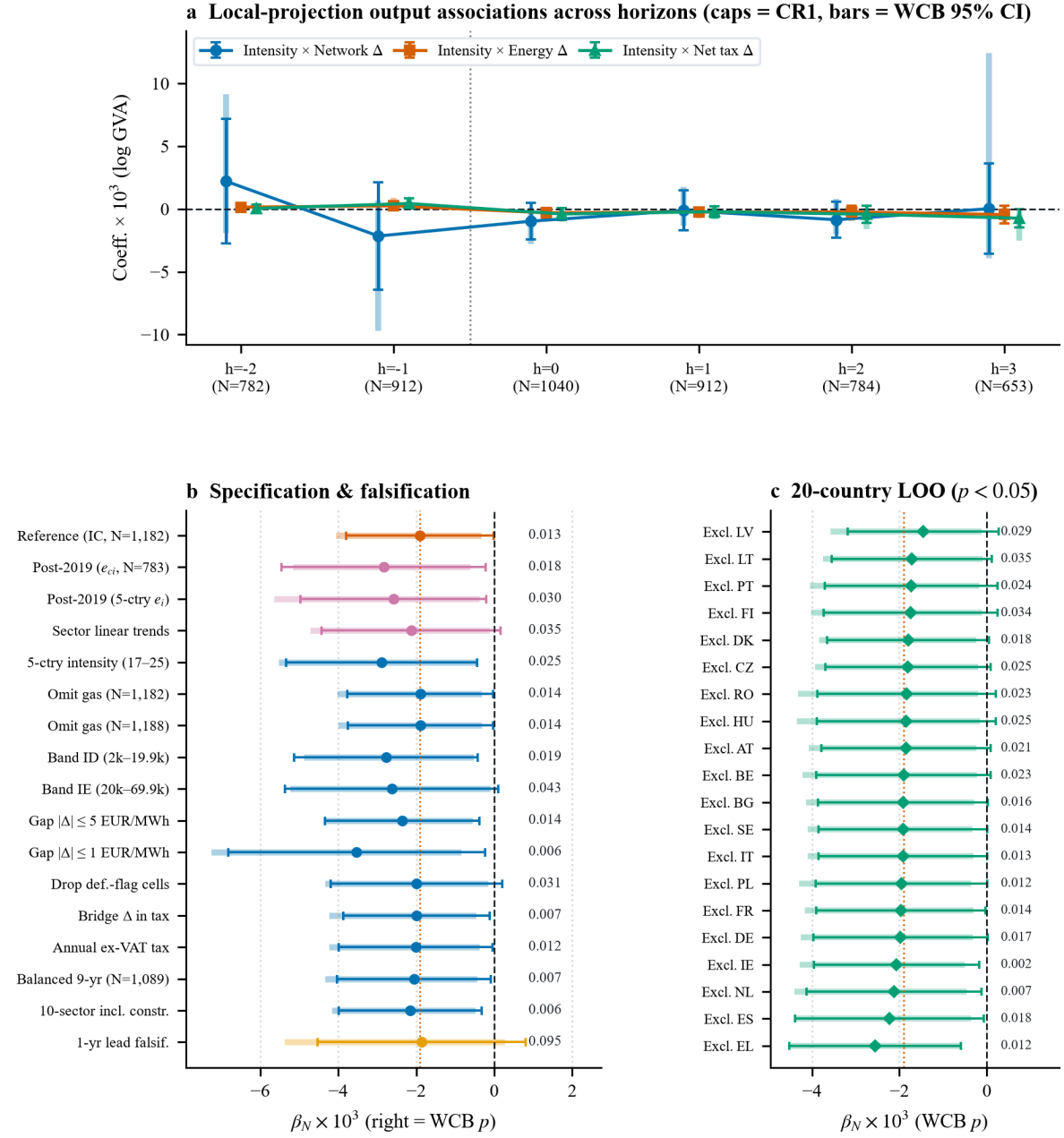


Figure 3. Dynamic local-projection output associations, specification forest plot, and leave-one-country-out jackknife stability.

Notes. Panel a displays conditional local-projection coefficients ($\theta_{k,h} \times 10^3$) from Equation (6) across horizons $h = -2$ to $h = 3$ years, showing conventional country-clustered 95% confidence intervals (thin capped lines) and unclipped inverted wild cluster bootstrap 95% confidence intervals (thick vertical bars) with exact horizon sample sizes N_h. Panel b plots the regulated network interaction ($\hat{\beta}_N \times 10^3$) with unclipped cluster and bootstrap 95% confidence intervals across 17 baseline, post-base-period, trend-augmented, band, reconciliation-audit, and full-sample lead-falsification specifications; the two small-sample pre-crisis lead windows ($N = 266$ and $N = 399$, reported in Table 4) are omitted from Panel b to preserve horizontal scale resolution. Panel c reports leave-one-country-out estimates omitting each of the 20 Member States ($G = 19$ clusters), with exact bootstrap p-values on the right.

mark electricity and gas intensities ($\bar{e}_i$, $\bar{g}_i$) yields −0.00259 (cluster $p = 0.0346$, bootstrap $p = 0.0298$, WCB 95% CI [−0.00565, −0.00038]; −0.00257 with benchmark electricity intensity alone, bootstrap $p = 0.0257$). On the full 2017–2025 window, the five-country electricity benchmark yields −0.00289 (cluster $p = 0.0234$, bootstrap $p = 0.0247$). Mechanical overlap with 2017–2019 nominal GVA denominators or endogenous domestic technology choices therefore cannot explain the baseline association.

2. **Secular exposure-trend controls.** Augmenting Equation (5) with linear time trends interacted with predetermined electricity and gas intensities ($e_{ci} \times t$ and $g_{ci} \times t$) yields $\hat{\beta}_N = -0.00213$ (SE = 0.00109, cluster $p = 0.0666$, bootstrap $p = 0.0348$, WCB 95% CI [−0.00471, −0.00012]) under domestic intensities and −0.00286 (cluster $p = 0.0268$, bootstrap $p = 0.0293$, WCB 95% CI [−0.00556, −0.00033]) under the five-country benchmark, ruling out smooth pre-existing decarbonization trends among electricity-intensive industries as the driver of the level estimate.
3. **Alternative industrial consumption bands and tariff-identity audits.** Replacing Band IC tariffs on the harmonized $N = 1{,}182$ sample with upper-medium Band ID (2,000–19,999 MWh) or large Band IE (20,000–69,999 MWh) yields $\hat{\beta}_N = -0.00277$ (bootstrap $p = 0.0192$) and $\hat{\beta}_N = -0.00262$ (bootstrap $p = 0.0430$). Restricting estimation to cells where the annual–semester reconciliation gap $|\Delta_{ct}|$ is at most 5 EUR/MWh ($N = 1{,}083$) or 1 EUR/MWh ($N = 859$) strengthens $\hat{\beta}_N$ to −0.00236 (bootstrap $p = 0.0144$, WCB 95% CI [−0.00438, −0.00055]) and −0.00353 (bootstrap $p = 0.0062$, WCB 95% CI [−0.00726, −0.00085]). Excluding observations carrying Eurostat definition-difference flags ($N = 1{,}140$, $\hat{\beta}_N = -0.00199$, bootstrap $p = 0.0312$), absorbing Δ_{ct} into the tax residual ($\hat{\beta}_N = -0.00199$, bootstrap $p = 0.0072$), or substituting the annual VAT-only-excluded tax component ($N = 1{,}166$, $\hat{\beta}_N = -0.00201$, bootstrap $p = 0.0118$) leaves inference unchanged.
4. **Balanced panel, ten-sector coverage, and country jackknife.** Restricting to balanced nine-year country–sector panels ($N = 1{,}089$, $G = 19$, omitting Poland due to its incomplete 2024 gas control) yields $\hat{\beta}_N = -0.00206$ (bootstrap $p = 0.0070$, WCB 95% CI [−0.00434, −0.00044]), and expanding to all ten manufacturing categories by adding fixed-GVA-weighted fabricated metals/machinery and rubber/plastics/other manufacturing ($N = 1{,}463$) yields $\hat{\beta}_N = -0.00215$ (cluster $p = 0.0238$, bootstrap $p = 0.0058$, WCB 95% CI [−0.00417, −0.00049]). Across all 20 leave-one-country-out regressions (Figure 3, Panel c), $\hat{\beta}_N$ remains strictly negative between −0.00256 (excluding Greece, bootstrap $p = 0.0116$) and −0.00146 (excluding Latvia, bootstrap $p = 0.0287$), with bootstrap p-values spanning [0.0018, 0.0354]—including −0.00180 when omitting Denmark (bootstrap $p = 0.0182$) and −0.00184 when omitting Romania (bootstrap $p = 0.0227$). Conventional $t(18)$ cluster p-values fall below 0.05 in 5 of 20 jackknife subsamples, illustrating small-cluster power differences when $G = 19$.
5. **Pre-trend lead falsification diagnostics.** In the bottom three rows of Table 4, we include one-year-ahead tariff leads ($e_{ci}N_{c,t+1}$) alongside contemporaneous tariff interactions. On the full 2017–2024 sample ($N = 1{,}054$), none of the three one-year-ahead electricity component leads is statistically significant at the 5% level (network lead −0.00186, SE = 0.00128, cluster $p = 0.1616$, bootstrap $p = 0.0954$, WCB 95% CI [−0.00537, 0.00026]; contemporaneous network −0.00105, bootstrap $p = 0.0674$). Similarly, on the strict pre-crisis window relating 2017–2018 output to 2018–2019 leads ($N = 266$), all three leads are statistically indistinguishable from zero (network lead −0.00666, SE = 0.00695, bootstrap $p = 0.1979$, WCB 95% CI [−0.02350, 0.00337]). However, extending the pre-crisis window to relate 2017–2019 output to 2018–2020 leads ($N = 399$, incorporating pandemic-year 2020 grid-charge adjustments) produces a negative network lead of −0.00588 (SE = 0.00404, cluster $p = 0.1621$, bootstrap $p = 0.0290$, WCB 95% CI [−0.01691, −0.00050]). As formalized in Equation (3), when industrial electricity load $Q_{c,2020}$ contracted sharply during 2020 in jurisdictions where heavy manufacturing was already decelerating, revenue-cap billing mechanically raised unit volumetric grid charges $N_{c,2020}$. Because reverse denominator feedback and anticipatory rate-case

adjustments remain active in observational country–year schedules, our estimates identify a robust medium-term conditional association distinct from an exogenous causal price elasticity.

7. Methodological Limitations

Four methodological boundaries govern the interpretation of our findings. First, as established in our statistical audit (Section 3), official European annual tariff components and semi-annual tax-tier series cannot be reconciled to exact zero discrepancy across all cells because semester delivery weights are unpublished and national statistical offices apply non-uniform algebraic signs to voluntary allowance memorandum lines. While our variance decompositions and regression estimates hold across narrow reconciliation-tolerance subsamples ($|\Delta_{ct}| \leq 1$ EUR/MWh) and all three price definitions, underlying non-VAT recoverable tax credits cannot be isolated from annual component filings alone.

Second, Eurostat consumption bands IA–IG classify reporting meters by annual electricity volume independently of establishment employment or firm ownership, and national band prices average across heterogeneous bilateral supply contracts. Consequently, attenuated coefficients on the energy-and-supply component ($\hat{\beta}_E$) in Table 3 may partly reflect measurement attenuation from unobserved long-term fixed-price power purchase agreements, industrial self-generation, and intra-group hedging among electro-intensive plants (Fontagné et al., 2024), while assigning national Band IC, ID, or IE schedules to two-digit industries abstracts from within-sector meter-size dispersion.

Third, public confidentiality suppression in two-digit industrial production and energy-balance statistics reduces our matched estimation sample from 27 to 20 Member States (excluding Cyprus, Estonia, Croatia, Luxembourg, Malta, Slovenia, and Slovakia), and requires combining iron and steel with non-ferrous metals into basic metals. External validity does not extend automatically to suppressed country–sector cells or sub-two-digit product lines.

Fourth, the statistically significant network lead in the extended 2017–2019/2020 pre-trend diagnostic (bootstrap $p = 0.0290$), the positive pre-change correlation between output growth and subsequent net tax adjustments ($h = -1$, bootstrap $p = 0.0220$), and the contrast between persistent level estimates and attenuated first-difference local projections confirm that volumetric grid charges and discretionary fiscal levies respond endogenously to industrial load and macroeconomic conditions. Identifying structural price elasticities of regulated network tariffs requires quasi-experimental variation from exogenous subnational distribution-zone boundary reforms or regulatory revenue-cap resets merged with plant-level microdata.

8. Conclusion and Regulatory Design Implications

Europe's post-2023 wholesale energy normalization did not restore cross-country industrial electricity tariff convergence. Across all 27 EU Member States and all three audited tariff definitions, an exact variance–covariance decomposition demonstrates that as energy and supply variance fell from 57.26% to 33.85% of Band IC delivered tariff variance between 2023 and 2025, regulated network charges doubled their variance share from 6.54% to 13.03%, net non-recoverable taxes reached 22.55%, and positive energy–network and energy–tax covariances accounted for 29.31% of remaining cross-border divergence. Paired national schedules in 2025 simultaneously imposed a 21.85 EUR/MWh regulated network surcharge and a 10.98 EUR/MWh net fiscal surcharge on medium-consumption manufacturing plants (Band IC) relative to large electro-intensive users (Band IF). Across 20 EU Member States and eight mutually exclusive manufacturing sectors over 2017–2025, predetermined electricity intensity interacted with regulated network charges exhibits a negative conditional association with real manufacturing output ($\hat{\beta}_N = -0.00191$, bootstrap $p = 0.0130$, Holm family-wise $p = 0.0390$), strengthening on the strictly post-base-period 2020–2025 sample ($\hat{\beta}_N = -0.00283$, bootstrap $p = 0.0177$) and surviving five-country

technological benchmarks, exposure linear trends, reconciliation subsamples, and all 20 country jackknife perturbations.

Keeping in view the medium-term associational scope established in Section 7, combining our descriptive tariff-dispersion audit with institutional regulatory mechanics highlights three policy design priorities for European energy governance. First, as shown by Equation (3) and established utility-pricing theory, recovering rising transmission reinforcement and congestion-management capital expenditures primarily through volumetric per-MWh network charges creates a pro-cyclical revenue-cap feedback loop in which industrial load contractions shrink the billing denominator and force upward unit grid tariff adjustments (Borenstein & Bushnell, 2022; Fabra, 2023). Rebalancing sunk grid cost recovery toward time-differentiated peak-coincident capacity subscriptions and general fiscal co-financing of public-good cross-border transmission investments offers a theoretically grounded mechanism to attenuate volumetric rate instability (Passey et al., 2017; Savelli & Morstyn, 2021). Second, our direct descriptive finding of a 32.83 EUR/MWh combined network-and-tax surcharge on Band IC relative to Band IF in 2025 shows that concentrating statutory exemptions in extra-high-consumption tiers exposes medium-scale manufacturing suppliers—such as specialized chemicals, paper processing, and fabricated metal producers—to steep non-energy tariff cliffs; evaluating smoother eligibility schedules tied to sectoral trade-and-electricity intensity merits regulatory scrutiny. Finally, our statistical audit demonstrates a concrete reporting reform for upcoming reviews of Regulation (EU) 2016/1952: mandating uniform negative-sign conventions for tax allowances and publishing semester delivery weights would eliminate annual–semester reconciliation gaps and enable transparent cross-border surveillance of non-household energy costs.

Statements

Data availability. Official industrial electricity and natural gas tariff decompositions, manufacturing production indices, energy balances, national accounts aggregates, and European Union legal acts used in this research come from Eurostat, EUR-Lex, and Statistics Denmark. All preserved raw extracts, country-sector estimation panels, identity-audit outputs, and reproduction scripts are permanently hosted on Zenodo at https://doi.org/10.5281/zenodo.24199771.

AI declaration. The authors used OpenAI Codex strictly as a technical aid for harmonizing official statistical tables and checking estimation code at the implementation level. Each author independently verified all assisted outputs; study design, econometric modeling, interpretation, and prose composition were carried out entirely by the authors, who accept full responsibility for the manuscript.

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