How Firms Pay for Energy Abatement: Evidence from India's Tradable Intensity Standard

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Abstract

How do firms respond to environmental regulation, and who bears the cost of abatement? I study India's Perform, Achieve and Trade (PAT) scheme, a plant-specific tradable energy-intensity standard covering the largest plants in eight energy-intensive sectors, about 60% of industrial energy use. I hand-digitise the Gazette of India notifications naming each designated plant and its target across eight cycles (2012–2023), and match them to a novel 26-year factory panel from the Annual Survey of Industries. Comparing designated plants with plants designated later but not yet, the regulated energy-output ratio falls 27% on average over six years, against a cumulative mandate of about 10%. Plants comply by changing what they use: materials spending rises 12% while the fuel bill falls 12%. Output does not fall. Profits, TFPR and labor productivity are unchanged. The cost surfaces in one price: the daily wage of permanent workers falls 7%, while contract wages at the same plants are flat, and the cut is steepest at plants that had to buy certificates. A model of the plant's compliance problem explains this incidence: a tradable intensity target set at the plant's own baseline is an energy tax plus an output subsidy that cancel at first order, so the abatement cost is second order and is cut from the permanent workers' wage premium.

JEL codes: Q58, Q48, D22, J31, O14.

Keywords: energy efficiency, tradable intensity standards, misallocation, rent sharing, India.

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1 Introduction

How do firms respond to environmental regulation, and what are the implications for productivity and growth? The question is acquiring urgency in developing countries, where industrial emissions are still rising and carbon markets are only now being built. India, the world's third-largest emitter, launched its first economy-wide carbon market in 2025. China's national emissions trading system has operated since 2021. Both are built on the same design: tradable, plant-specific intensity targets. How firms absorb such standards, on which margins, and at whose expense, is an open empirical question.

The existing evidence on how firms absorb environmental regulation comes mostly from advanced economies and points to three margins of adjustment: innovation, wages, and location. On innovation, Aghion, Dechezleprêtre, Hemous, Martin, and Van Reenen (2016) document induced clean innovation in the automobile industry, and Calel and Dechezleprêtre (2016) find the EU Emissions Trading System raised low-carbon patenting among regulated firms, while Greenstone, List, and Syverson (2012) measure modest productivity losses from air quality regulation in US manufacturing. A second literature links firm-level regulation to worker outcomes using administrative data: Walker (2013) finds substantial earnings losses for workers in newly regulated industries, and Fuster, Kabas, Pezone, and Roszbach (2025) and Fontaine, Marullaz, and Schubert (2026) trace the pass-through of environmental compliance costs to wages in Europe. A third margin is relocation: firms move activities across borders (Martin, Muuls, de Preux, and Wagner, 2014; Hanna, 2010), or more broadly outside the boundary of the firm. In developing countries these margins are narrower: capital is costly, retrofitting is often infeasible, and access to green technology is lower (Verhoogen, 2023), so the same regulation may produce a different response.

The margin on which firms respond also determines whether abatement policy misallocates resources across plants, which is the aggregate question the macroeconomic literature on environmental policy has raised. Tombe and Winter (2015) show that a *common* intensity standard is an energy tax plus an implicit output subsidy: because plants differ, the subsidy misallocates inputs across firms and sectors, and intensity standards are dominated by uniform taxes, with large calibrated productivity losses. Klenow, Pastén, and Ruane (2025) show that with pre-existing distortions a carbon tax has first-order allocative effects. In Chile fuel intensity is negatively correlated with markups, so a carbon tax reallocates activity toward high-markup plants and raises allocative efficiency. Greenstone, Pande, Ryan, and Sudarshan (2025) show experimentally, in Surat's particulate-emissions market, that allowing trades lowers abatement costs relative to command-and-control. I study an intensity target where firms can trade, and measure the allocative consequences directly at the plant

level.

This paper studies India's Perform, Achieve and Trade (PAT) scheme, a tradable energy-intensity standard applied plant by plant, which was launched in 2012 and covers the largest plants in eight energy-intensive, hard-to-abate sectors, about 60% of industrial energy use. Two features distinguish PAT from the policies in the literature above. First, the target is a ratio, energy per unit of output, not a cap on energy: a plant can comply by using less energy, by producing more with the same energy, or by changing what it makes and buys. Second, the target is set against each plant's *own* audited baseline, not a common benchmark, a design choice that turns out to govern the policy's allocative footprint.

The plant-level evaluation is possible because of two datasets that I construct for this paper. I hand-digitise the Gazette of India notifications that name every designated plant and its target, across all eight PAT cycles from 2012 to 2023. I also construct a 26-year plant panel (1998–2023) from the Annual Survey of Industries covering fuel use by type, physical quantities, output, capital, employment and wages by worker type, materials, and product-level quantities and prices. Matching the gazette plants to the anonymised ASI yields 397 designated plants observed through the policy period. For each outcome I compare designated plants with plants designated *later* but not yet, using the difference-in-differences estimator of de Chaisemartin and D'Haultfœuille (2026): every control is a future designee, so selection into the programme is held fixed, and placebo horizons test the parallel-trends assumption directly.

The first result is that designated plants reduced their regulated energy-output ratio by far more than their targets required. The ratio falls 27% on average over the six years after designation, and 43% by year six, against a cumulative mandate of roughly 10%. The response combines both margins of the ratio: the fuel bill falls 12% in levels while output drifts up about 5%. Consistent with over-compliance, the certificate market was over-supplied and the certificate price fell to its floor.

The second result is that plants complied by buying more of other inputs rather than by producing less. Spending on materials and other intermediates rises 12%. Capital and employment rise by less, 6% and 3%. No input falls except energy. The product-level data show the recipe changes behind the aggregate, sector by sector, with the energy-intensive stage moving outside the plant.

The third result is that the policy left no trace on the plant's profits or productivity. The profit rate and the profit margin do not move. Revenue productivity (TFPR) is unchanged, with a confidence interval that excludes changes larger than about 4%. Physical productivity and value added per worker are flat. The policy leaves no footprint on the plant's books, with one exception.

The one price that did move is the wage of the plant's permanent workers, the part of pay that is set in the plant's wage settlement. The daily wage of permanent production workers falls 7% after designation, and 12% by year six. The wage of contract workers at the same plants, hired through contractors at the market rate, does not move. The cut follows the compliance bill: plants that fell short of their targets and had to buy certificates cut the permanent wage 12%, while plants that over-complied and sold certificates cut 1%.

To interpret this pattern of incidence, I write down the plant's compliance problem and show that it explains why the cost of the policy appears in the bargained wage and nowhere else. Attaching a multiplier to the intensity constraint shows the policy is an implicit tax on energy plus an implicit subsidy on output, both at the plant's shadow price. The subsidy is scaled by the plant's own audited baseline, so the two flows cancel at the target: the policy has no first-order effect on the plant's costs, and measured TFPR cannot move, which is what the data show. What survives is the second-order cost of running a leaner input mix, about 0.03% of the total bill at the mean cut and 0.3% at the deepest cuts, a number that can also be computed exactly from two observed energy shares using the weights of Sato (1976) and Vartia (1976), with no elasticity estimated. Within the horizon of the plant's wage settlement the owners' claim is fixed, so the whole abatement cost passes through to the premium pool paid to the fixed permanent workforce: a cost invisible in profits is a visible cut in the one price that is a residual.

These results carry a lesson about the design of intensity standards that extends beyond India. A tradable intensity target set at each plant's own baseline creates no first-order distortion across plants, in contrast to the common-benchmark standard of Tombe and Winter (2015); its aggregate cost is the abatement spending itself, which is second order. The incidence falls on whoever holds the residual claim inside the plant. India's Carbon Credit Trading Scheme inherits PAT's architecture and its list of plants, so these results speak directly to the carbon market now scaling up.

The paper proceeds as follows. Section 2 describes the policy. Section 3 describes the gazette digitisation, the ASI panel, and the match between them. Section 4 presents the empirical strategy. Section 5 presents the results: compliance, the input mix, profits and productivity, and wages. Section 6 presents the model and its extensions to certificate trading and to the energy-materials elasticity. Section 7 concludes.

2 Institutional Background

2.1 The PAT Scheme

PAT rests on the Energy Conservation Act of 2001, which established the Bureau of Energy Efficiency (BEE) under the Ministry of Power. The Act empowered the central government to designate energy-intensive establishments as Designated Consumers subject to mandatory energy audits and compliance reporting. The 2008 National Action Plan on Climate Change established the National Mission for Enhanced Energy Efficiency, under which the PAT scheme was launched in 2012, the first market mechanism for environmental regulation at the national level.

Plants do not opt into PAT: designation is determined by the level of a plant's energy use. A plant is designated if its annual energy consumption exceeds a sector-specific threshold, ranging from 3,000 tonnes of oil equivalent (toe) for textiles to 100,000 toe for petrochemical crackers. Plants above the threshold are mandated to participate; plants below are exempt. Designation operates at the plant, not the firm: multi-plant firms appear as separate entries with distinct targets.

The obligation is defined as a ratio, energy per unit of output, and the required cut is taken from the plant's own past performance. Each designated plant receives a plant-specific reduction target for its specific energy consumption (SEC), the ratio of energy used to output produced. BEE establishes each plant's baseline SEC as the three-year average prior to the cycle, normalised for factors outside the plant's control: capacity utilisation, power mix, fuel quality, and product mix. Plants with high baseline SEC receive steeper reduction targets, while plants already near sectoral best practice receive smaller ones. The mandate takes the form Target SEC = Baseline SEC $\times(1 - r_i)$, where r_i is the plant-specific fractional reduction, typically 4–8% over a three-year cycle. The list of designated plants and their targets is published in the Gazette of India for each cycle.

2.2 Certificates and Compliance

Certificate trading gives the target a market price. At the end of each compliance cycle, plants undergo measurement and verification by accredited energy auditors. Plants that achieve SEC below their target earn Energy Saving Certificates (ESCerts) proportional to overachievement, where one ESCert represents one tonne of oil equivalent saved. Plants that miss their targets must purchase ESCerts from overachievers on the Indian Energy Exchange or Power Exchange India, overseen by the Central Electricity Regulatory Commission. ESCert prices have fluctuated between Rs 200 and Rs 1,200 per certificate, determined by a

double-sided uniform price auction.[1] Plants that neither meet targets nor purchase sufficient certificates face a fine of Rs 10 lakhs plus a penalty equal to the price of the energy shortfall.

Compliance was the norm. In BEE's own verified numbers for Cycle I, published in February 2017, 306 of 478 designated plants (64%) met their targets and were issued 3.8 million ESCerts. 110 plants (23%) fell short and were directed to buy 1.4 million ESCerts, and 96% bought, an ESCert costing 0.05 to 0.3% of a year's fuel bill; the remainder are not in the release. Cycle I achieved total verified savings of 8.67 Mtoe, exceeding its 6.6 Mtoe target. The oversupply of certificates from widespread over-compliance pushed the ESCert price toward its floor.

2.3 Cycles and the Transition to the Carbon Market

BEE notified eight PAT cycles between 2012 and 2023, and these cycles were of two kinds. Cycle I (2012–15) covered 478 plants across all sectors, including thermal power stations, railways and electricity distribution companies. The rollout then expanded in two distinct ways. Re-notification waves deepened targets for existing plants: the original designees received fresh cuts in Cycle II (2016) and again in Cycle VII (2022). Expansion waves designated new plants: Cycles III–VI and VIII lowered thresholds and added sectors without reassigning the incumbents. In the digitised gazette data, the mean assigned cut is stable at about 5% per notification, and a plant's cumulative mandate compounds to about 10% by its second notification and 14% by its third. Once designated, a plant stays in the scheme: its most recent target remains its applicable norm until a new notification supersedes it, and its next baseline is re-audited from its then-current performance, so over-compliance in one cycle tightens the ask in the next.

Since 2025, PAT's architecture has formed the compliance core of India's carbon market. In that year the scheme was absorbed into the Carbon Credit Trading Scheme (CCTS), the country's first economy-wide carbon market. The compliance unit shifts from energy to emissions intensity, but the plant-level, intensity-target, own-baseline design carries over, and the list of obligated entities is built from PAT's designated consumers.

3 Data

The evaluation rests on two datasets I build: the plant-level regulatory assignments, digitised from Gazette of India notifications spanning eight PAT cycles, and a 26-year factory panel

[1] In Cycle I, 1.29 million ESCerts were traded in 17 sessions, amounting to approximately $12 million (Pal, Mukhopadhyay, and Bhagawan, 2024).

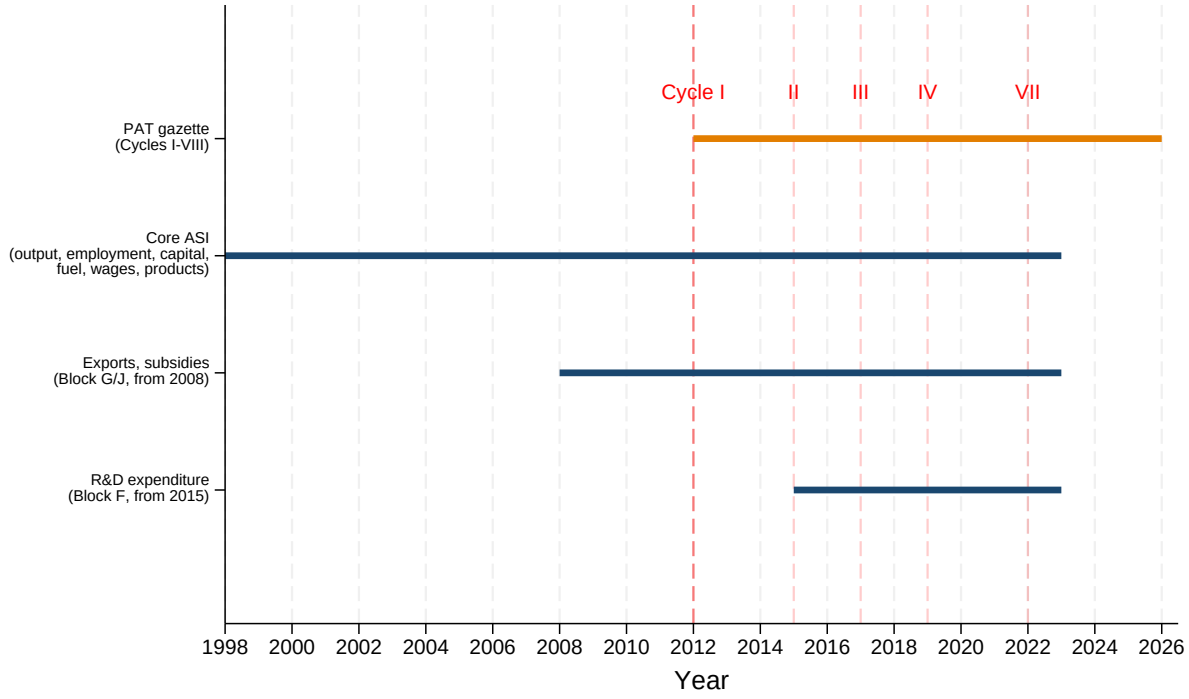


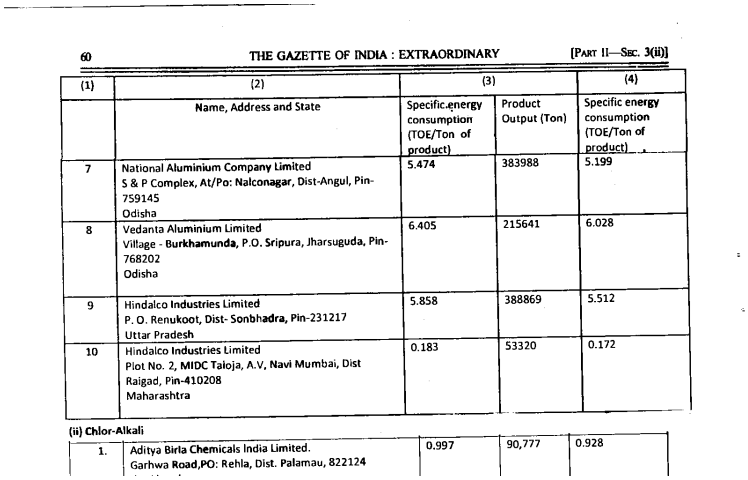
Figure 1: Data Coverage and PAT Regulatory Timeline

Notes: Horizontal bars show the coverage of each data source. The core ASI variables (output, employment, capital, fuel, wages, products) span 1998–2023. Vertical dashed lines mark the start of each PAT cycle. The ASI panel provides 14 pre-treatment years for Cycle I and over a decade of post-treatment years. Gazette notifications are available for all eight cycles.

constructed from the Annual Survey of Industries.

3.1 The Digitised Gazette

No dataset of PAT assignments existed, so I build one from the primary legal source, the Gazette of India. Each PAT cycle is notified through a Statutory Order published in the Gazette of India, which lists every Designated Consumer by firm name and location, with its registration code, sector, baseline SEC, product output, and SEC reduction target. I obtain the original gazette PDFs, many bilingual in Hindi and English, from BEE's public archives and extract the English-language tables. Where machine extraction is possible I use the Excel-format circulars published alongside the notifications, and where it is not I digitise manually from the PDF tables. I validate the digitised data by cross-referencing the extracted tables against BEE's published circulars. Where both sources exist, plant counts match exactly. To my knowledge this is the first systematic digitisation of the full set of PAT gazette notifications for research purposes.



60 THE GAZETTE OF INDIA : EXTRAORDINARY [PART II—SEC. 3(ii)]

(1)	(2)	(3)		(4)
	Name, Address and State	Specific energy consumption (TOE/Ton of product)	Product Output (Ton)	Specific energy consumption (TOE/Ton of product)
7	National Aluminium Company Limited S & P Complex, At/Po: Nalconagar, Dist-Angul, Pin-759145 Odisha	5.474	383988	5.199
8	Vedanta Aluminium Limited Village - Burkhamunda, P.O. Sripura, Jharsuguda, Pin-768202 Odisha	6.405	215641	6.028
9	Hindalco Industries Limited P. O. Renukoot, Dist- Sonbhadra, Pin-231217 Uttar Pradesh	5.858	388869	5.512
10	Hindalco Industries Limited Plot No. 2, MIDC Taloja, A.V, Navi Mumbai, Dist Raigad, Pin-410208 Maharashtra	0.183	53320	0.172
(ii) Chlor-Alkali				
1.	Aditya Birla Chemicals India Limited. Garhwa Road,PO: Rehla, Dist. Palamau, 822124	0.997	90,777	0.928

Figure 2: Gazette of India Notification, PAT Cycle I

Notes: A page of notification S.O. 687(E) (30 March 2012). Column 2 names each Designated Consumer by name, address and state; column 3 reports the baseline specific energy consumption and output; column 4 reports the target SEC. Every regulated plant is listed individually.

Each row of a gazette notification states the policy for one plant in the terms the model uses. Figure 2 reproduces a page of the Cycle I notification: column 3 gives the plant's baseline energy per tonne and its output, column 4 gives the target. Targets are set at the plant level and vary according to how the plant performs relative to its sector: in the aluminium rows shown, NALCO's Angul complex is assigned a 5.0% cut and Hindalco's Taloja plant 6.0%. Across all cycles the assigned cuts average 5.3% with a median of 5.2%, with substantial right-tail variation across plants within sector. For the six manufacturing sectors comparable in the ASI (aluminium, cement, chlor-alkali, iron and steel, pulp and paper, textiles), the gazette yields 711 plant designations across the eight cycles.

3.2 The ASI Factory Panel

I build the longest available factory-level panel from the Annual Survey of Industries (ASI): 26 years, 1998–2023. The ASI covers all factories registered under the Factories Act, 1948. I restrict the analysis to the *census stratum*, factories with 100 or more workers, surveyed every year with sampling weight one, which contains 533,419 factory-year observations. This is a design choice as much as a sample restriction: PAT regulates the largest industrial energy consumers, which fall in the census stratum, and these factories are observed every operating year. Prior studies using the ASI panel typically cover 5–15 years (e.g., Allcott, Collard-Wexler, and O'Connell, 2016; Abeberese, 2017; Martin, Nataraj, and Harrison, 2017; Hsieh and Klenow, 2009); Chakraborty and Chatterjee (2017) use ASI data to study environmental regulation in India.

The panel records every margin on which a plant can comply with an intensity target. The ASI provides item-level fuel expenditure (coal, petroleum, electricity, gas), physical fuel quantities, output and sales, capital, employment and wages separately for directly employed and contract workers, intermediates, and product-level quantities and unit values. From the Block H quantities and the fuel bill I construct each plant's energy use in tonnes of oil equivalent, the unit of the gazette targets, so the regulated ratio itself is an outcome I observe.[2] I compute value added per worker, subtracting energy as an input, and revenue productivity (TFPR) as revenue over total cost at market prices, with capital services priced at $R = 0.10$ and energy kept as a separate input.

3.3 Matching Gazette Plants to the ASI

The ASI is anonymised: it carries state, industry, ownership and size, but no name. The gazette has the name. I look for each designated plant among the ASI factories that look like it: within the plant's state, industry and ownership class, I take the census factory whose size ranks where the plant's gazette output ranks, assigning multi-plant firms jointly, largest to largest. Each match is assigned a quality tier. Tier A matches have a single candidate: NALCO Angul is the only government-owned aluminium factory of its size in Odisha. Tier B matches have several similar candidates, and the closest is taken: Hindalco Taloja is one of a few private aluminium factories of its size in Maharashtra. Tier C plants have no plausible candidate, usually because the plant is younger than the panel, and are dropped. Of the 711 gazette designations in the six ASI-comparable sectors, 419 match an ASI factory (68 Tier A, 341 Tier B, 9 Tier C). The analysis sample is the 397 Tier A and B plants observed in the cleaned panel. Table 1 describes them in the pre-policy years 2008–11. The typical designated plant is large, with mean output of Rs 1,700 crore and about 2,450 employees, and energy-intensive, with fuel accounting for 16% of its input bill on average. Contract workers are half of its workforce and earn about 60% of the permanent daily wage. The assigned cut in a plant's first cycle averages 5.6%, ranging from 1.4% to 15%.

4 Empirical Strategy

Designation is staggered: plant i enters in cycle year g_i (2012, 2016, 2017, ...), and remains in the scheme once in. For each horizon ℓ, I compare designated plants with plants designated *later* but not yet, using the difference-in-differences estimator of de Chaisemartin and

[2] Fuel-specific conversion factors are calibrated on the gazette-matched Cycle I plants over BEE's baseline years. A quantity-only measure using coal tonnes, kWh and gas gives similar results.

Table 1: Designated Plants Before the Policy, 2008–2011

Series	Mean	SD	Min	Max	N
Output (Rs crore)	1,720.7	3,020.8	1.0	19,892.4	235
Employees	2,451	3,659	2	28,120	235
Fixed capital (Rs crore)	1,661.6	3,663.5	18.5	29,493.7	235
Materials and intermediates (Rs crore)	1,008.0	1,890.9	0.1	13,187.5	235
Fuel expenditure (Rs crore)	171.7	295.2	0.1	1,646.5	235
Energy use (thousand toe)	225.9	495.1	0.1	3,698.0	235
Fuel expenditure / output	0.146	0.402	0.003	6.098	235
Energy cost share	0.159	0.141	0.001	0.549	235
Permanent wage per manday (Rs)	478	387	57	3,755	228
Contract wage per manday (Rs)	285	423	70	5,427	200
Contract share of workers	0.533	0.265	0.002	0.990	192
Assigned SEC cut, first cycle	0.056	0.016	0.014	0.151	190

Notes: Plant-level means over the years 2008–2011 for the gazette-matched designated plants (Tier A+B) observed in those years, computed from the ASI census stratum. Output, fixed capital, materials and fuel expenditure are in rupees crore. Energy use is the plant's fuel use in tonnes of oil equivalent, constructed from Block H quantities and the fuel bill. The energy cost share is fuel expenditure over the sum of fuel, materials and intermediates, wages and capital services at $R = 0.10$, the object $s_{E,i}$ of the model. Wages per manday are Block E wage bills over mandays for directly employed and contract workers. The assigned cut is the SEC reduction target in the plant's first designation cycle, from the gazette.

D'Haultfœuille (2026):

$$\widehat{\delta}_\ell = \sum_g w_g \Big\{ \big(\bar{y}_{g+\ell}^{\,g_i=g} - \bar{y}_{g-1}^{\,g_i=g}\big) - \big(\bar{y}_{g+\ell}^{\,g_i>g+\ell} - \bar{y}_{g-1}^{\,g_i>g+\ell}\big) \Big\}, \qquad \ell \in \{1,\dots,6\}, \tag{1}$$

with y in logs, $g-1$ the reference year, and cohort weights w_g. The building block is a two-by-two: the treated cohort's change from the year before designation to ℓ years after, less the change of not-yet-treated plants over the same calendar window. The reported average effect is $\bar{\delta} = \frac{1}{6}\sum_{\ell=1}^{6} \widehat{\delta}_\ell$.

The comparison group consists entirely of plants that will themselves be designated in a later cycle. The estimator restricts controls to the not-yet-treated, avoiding the contaminated comparisons that two-way fixed effects make under staggered adoption (de Chaisemartin and D'Haultfœuille, 2020). The restriction also has an economic content here: every control plant is a future designee that passed the same designation rule, so the comparison is made within the population the rule selects, and only the timing of designation differs. The timing is driven by BEE's sector-by-sector rollout of thresholds, not by the plant's own choices. Four placebo horizons $\ell < 0$, estimated by running the same construction backwards, test the parallel-trends assumption. They are jointly insignificant throughout. The sample is the 397 gazette-matched census plants, 1998–2023, with standard errors clustered by plant.

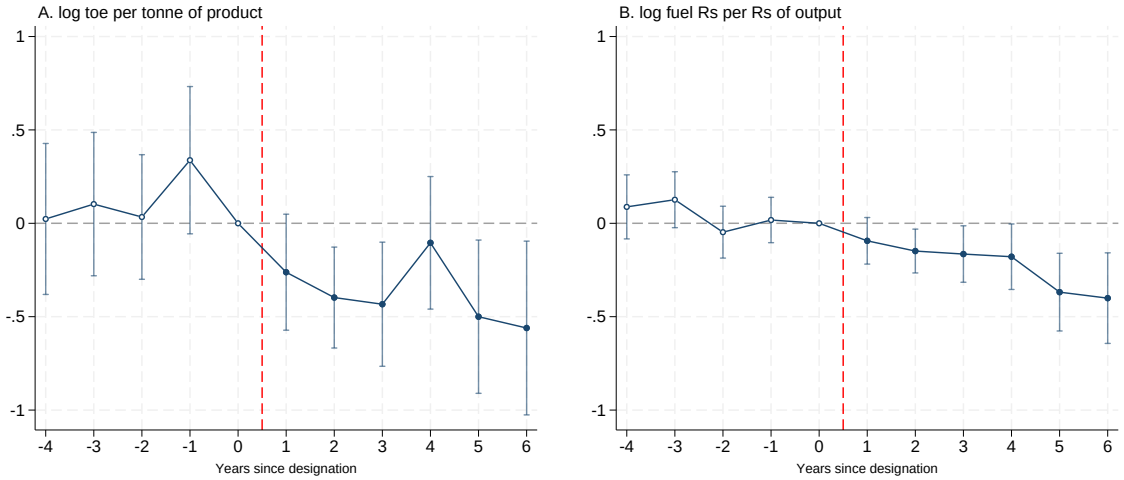


Figure 3: The Regulated Ratio After Designation

Notes: 397 gazette-matched designated plants (Tier A+B); panel A pools cement, steel and paper, the sectors whose main product is reported in tonnes; panel B uses all plants. The y axis is the log outcome: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation; the year before designation is the reference, and hollow markers are placebo years. Standard errors are clustered by plant. Average effects over years 1–6: A −0.311 (0.120), a 27% decline; B −0.175 (0.057), a 16% decline.

5 Results

A designated plant can respond in three ways: comply, by bringing E_i/Q_i to its target or below, earning tradable certificates for savings beyond the target; fall short and buy certificates equal to the shortfall; or fall short and pay the statutory penalty. The results trace what compliance did to the plant: first the regulated ratio, then the input mix that produced it, then the plant's books, then its wages.

5.1 Compliance and the Regulated Ratio

After designation, plants reduced the regulated ratio by more than a quarter relative to plants not yet designated. Figure 3 shows the result: panel A plots event-study coefficients for the regulated ratio, energy in toe per tonne of the main product, for the sectors whose output is reported in tonnes (cement, steel, paper). Panel B plots fuel expenditure per rupee of output for all 397 plants. The regulated ratio falls 27% on average over the six years after designation (coefficient −0.311, standard error 0.120), and the gap is still widening: 43% by year six. The per-rupee measure falls 16% (−0.175, s.e. 0.057). The pre-designation placebos are flat in both panels.

The decline is considerably larger than the mandated reduction. The cumulative assigned

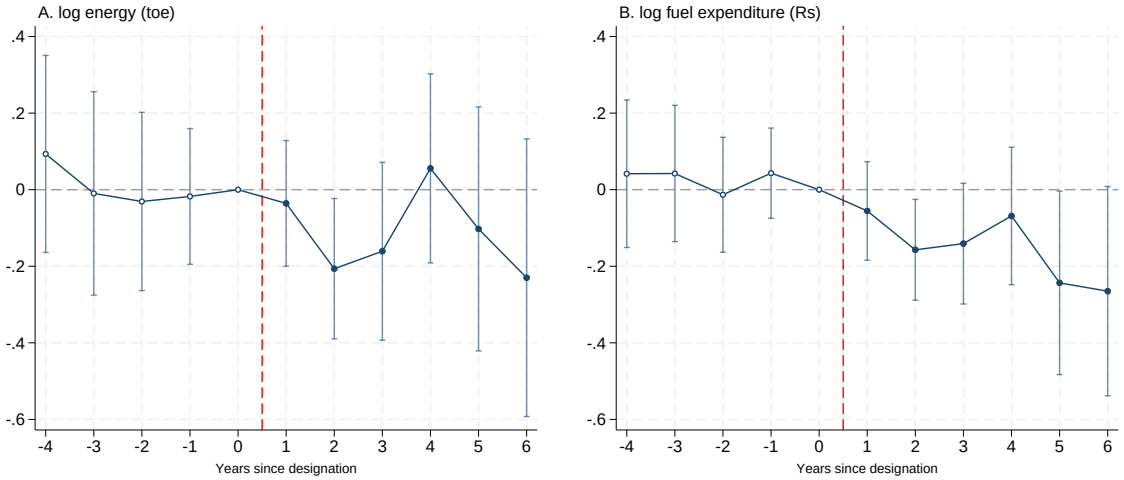


Figure 4: Energy Use and the Fuel Bill in Levels

Notes: 397 gazette-matched designated plants (Tier A+B); the outcomes are levels, not ratios. The y axis is the log outcome: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation. Standard errors are clustered by plant. Average effects over years 1–6: energy in toe −0.095 (0.084), a 9% decline; fuel expenditure −0.123 (0.061), a 12% decline.

cut for an early designee is about 10% by year six. Plants delivered roughly three times that. Over-compliance is what the instrument pays for: a tradable standard rewards every tonne saved beyond the target with a sellable certificate, so the plant abates to the point where its marginal abatement cost meets the certificate price, not to the target. The market confirmed the arithmetic in equilibrium: certificates flooded in and the ESCert price fell toward its floor (Section 2).

The fall in the ratio reflects movement in both its numerator and its denominator. Figure 4 shows energy in levels: the fuel bill falls 12% on average (−0.123, s.e. 0.061) and 23% by year six, and energy in toe falls 9% (−0.095, s.e. 0.084). The saving is a quantity, not a price: it is there in toe as well as in rupees. Figure 5 shows the other margin: the value of output drifts up about 5% (+0.051, s.e. 0.047), and physical tonnes of the main product rise where tonnes are recorded (+0.095, s.e. 0.089). Value per tonne is flat, so the drift is quantity, not price. Plants did not shrink to comply.

5.2 The Compliant Input Mix

The energy that plants stopped using was replaced by purchased materials. Figure 6 shows spending on raw materials and other intermediates rises 12% after designation (+0.118, s.e. 0.056), and the ratio of materials to the fuel bill rises 25% (+0.251, s.e. 0.063), the substitution margin the intensity target prices. Figure 7 shows capital and employment:

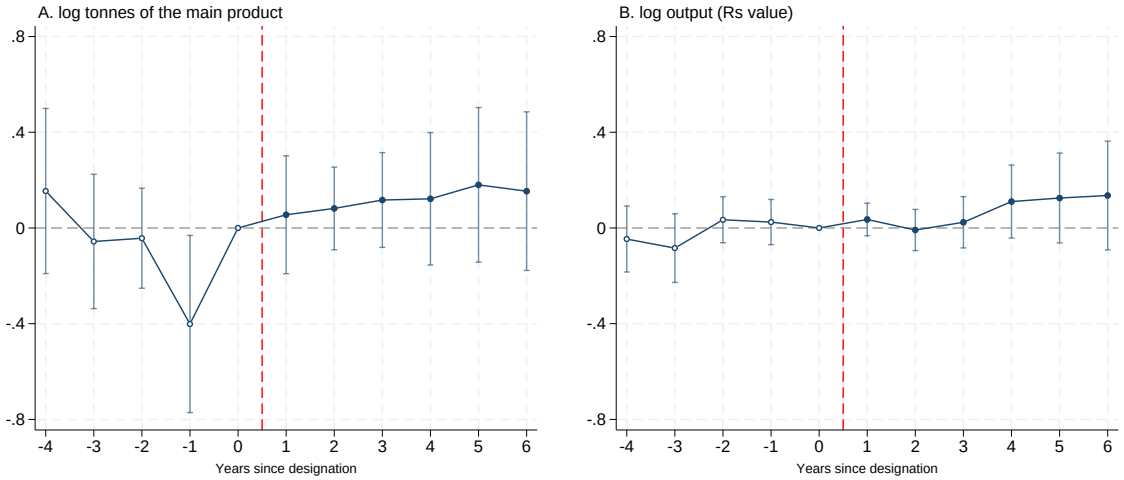


Figure 5: Output in Tonnes and in Rupee Value

Notes: 397 gazette-matched designated plants (Tier A+B); panel A pools cement, steel and paper, the sectors whose main product is reported in tonnes; panel B uses all plants. The y axis is the log outcome: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation. Standard errors are clustered by plant. Average effects over years 1–6: A +0.095 (0.089), a 10% increase; B +0.051 (0.047), a 5% increase.

fixed capital drifts up 6% (+0.055, s.e. 0.034) and employment 3% (+0.034, s.e. 0.036); contractions beyond about 1% of capital and 4% of employment are ruled out at the 95% level. Plants did not meet the target by shedding capacity or workers, and the mix of workers does not change: the shares of contract workers, supervisory staff and other employees are flat.

The product-level data show the recipes behind the aggregate: in each sector the compliant recipe is bought, as the plant substitutes purchased intermediates that embody the energy it no longer burns.[3]

5.3 Profits and Productivity

The reduction in energy use was not financed out of profits (Figure 8). Profit is the gross operating surplus, value added less labour cost. Neither the return on fixed capital (−0.017,

[3]Designated cement plants raised the blended share of their cement sales (pozzolana and slag cements replace part of the clinker with fly ash and slag, cutting energy per tonne at the same kiln), with an average effect of +6.3 percentage points (s.e. 4.1) on a 2011 baseline of 11%, and did not start buying clinker. Paper plants fed more waste paper and bagasse, which need no pulping, raising the recycled share of input value by 8.2 percentage points (s.e. 5.2) on a baseline of 26%. Aluminium plants raised the purchased-alumina share of inputs and cut bauxite, shifting the thermal refining stage to suppliers, though with only twelve plants the intervals are wide. Shares use the NPCMS product and input codes, available from 2010, and each sector is compared with plants of all sectors designated later but not yet.

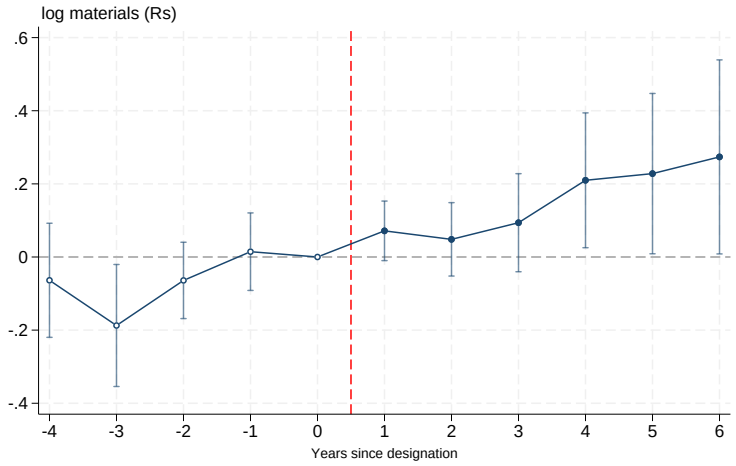


Figure 6: Materials Spending After Designation

Notes: 397 gazette-matched designated plants (Tier A+B); the outcome is spending on raw materials and other intermediates. The y axis is the log outcome: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation. Standard errors are clustered by plant. Average effect over years 1–6: +0.118 (0.056), a 12% increase.

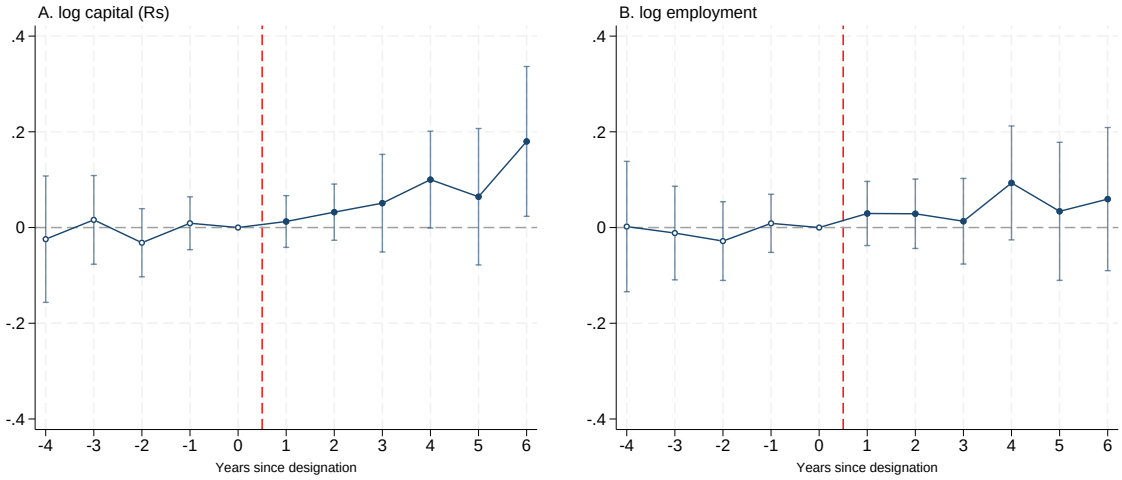


Figure 7: Capital and Employment After Designation

Notes: 397 gazette-matched designated plants (Tier A+B); the outcomes are net book fixed capital and total employees. The y axis is the log outcome: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation. Standard errors are clustered by plant. Average effects over years 1–6: capital +0.055 (0.034), a 6% increase; employment +0.034 (0.036), a 3% increase.

s.e. 0.032, on a 2011 baseline of 0.49) nor the margin on output (−0.004, s.e. 0.011, on a baseline of 0.26) moves after designation; the margin interval rules out a change of more than two points on a 26 percent base.

Nor does the plant's productivity show any cost of compliance (Figure 9). Value added

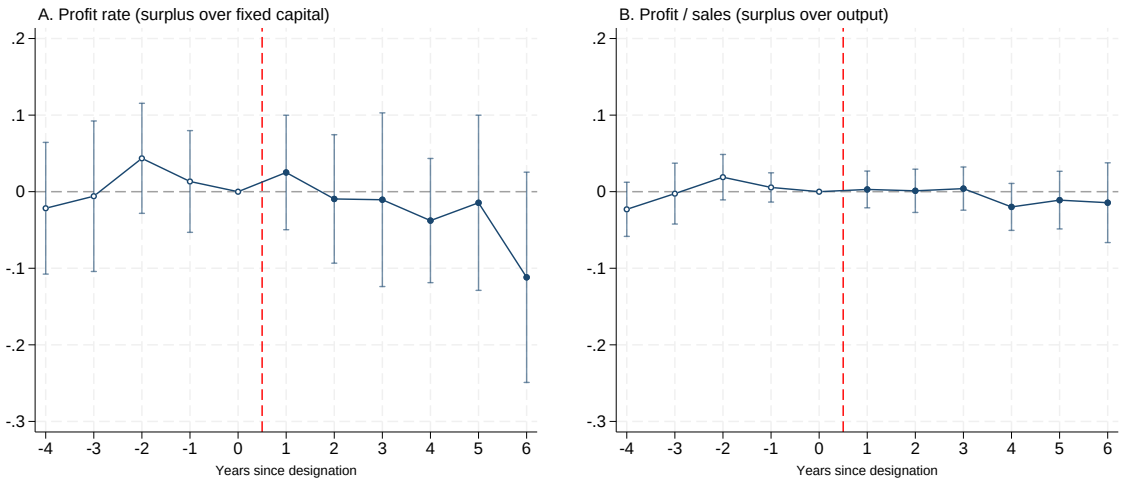


Figure 8: Profit Rate and Profit Margin After Designation

Notes: 397 gazette-matched designated plants (Tier A+B); ratios winsorised at the 1st and 99th percentiles. The y axis is the ratio in levels: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation. Standard errors are clustered by plant. Average effects over years 1–6: profit rate −0.017 (0.032); profit over sales −0.004 (0.011).

per employee is flat (−0.024, s.e. 0.054): with output drifting up and the extra materials bill offsetting the fuel saving, value added stays where it was, and headcount does not move. Revenue productivity is flat and precisely estimated: TFPR, measured as revenue over total cost at market prices, moves −0.011 (s.e. 0.014), an interval that excludes declines larger than about 4%. Physical productivity confirms it both ways: TFPQ with cost-share weights moves −0.018 (s.e. 0.030), and tonnes per employee, which needs no deflator and no cost shares, moves +0.076 (s.e. 0.083). The wage result that follows is not lower productivity.

5.4 Wages

Designated plants employ two kinds of shop-floor workers, and the policy affected the pay of only one of them: permanent workers on the rolls, covered by the plant's wage settlement, and contract workers paid the going rate through a contractor. Before PAT, a permanent production worker at a designated plant earned Rs 370 per day at the median against Rs 195 for a contract worker at the same plant. Figure 10 shows what designation did to each. The daily rate of permanent workers falls 7% on average (−0.069, s.e. 0.032) and 12% by year six; the contract rate at the same plants does not move (−0.018, s.e. 0.035). The local market for labour did not soften; the part of pay that is bargained did.

The size of the wage cut tracks the plant's cost of compliance. Certificate positions are audited and predetermined: BEE's Cycle II baseline against the Cycle I target, not my

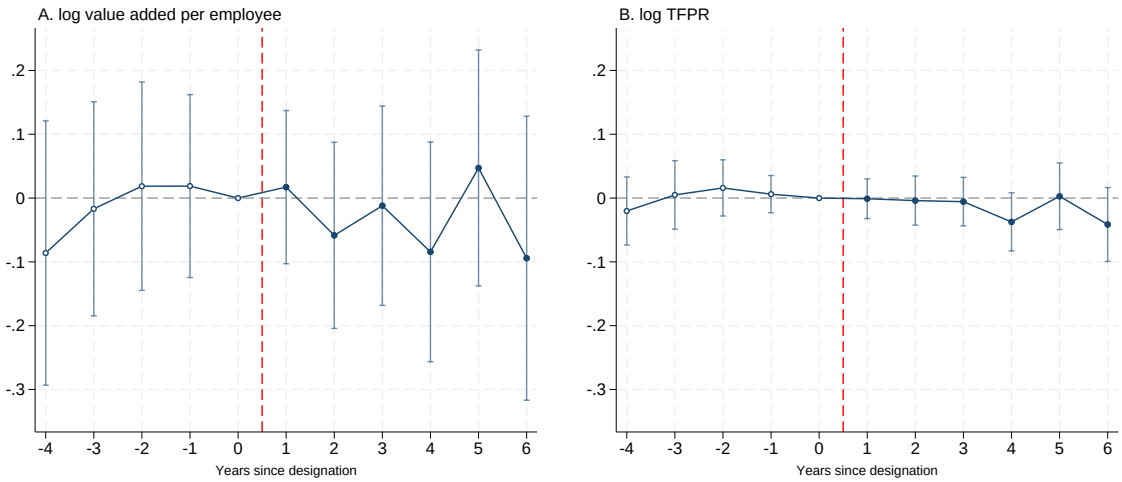


Figure 9: Value Added per Worker and TFPR After Designation

Notes: 397 gazette-matched designated plants (Tier A+B); TFPR is revenue over total cost at market prices, with capital services at $R = 0.10$ and energy as a separate input. The y axis is the log outcome: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation. Standard errors are clustered by plant. Average effects over years 1–6: value added per employee −0.024 (0.054); TFPR −0.011 (0.014).

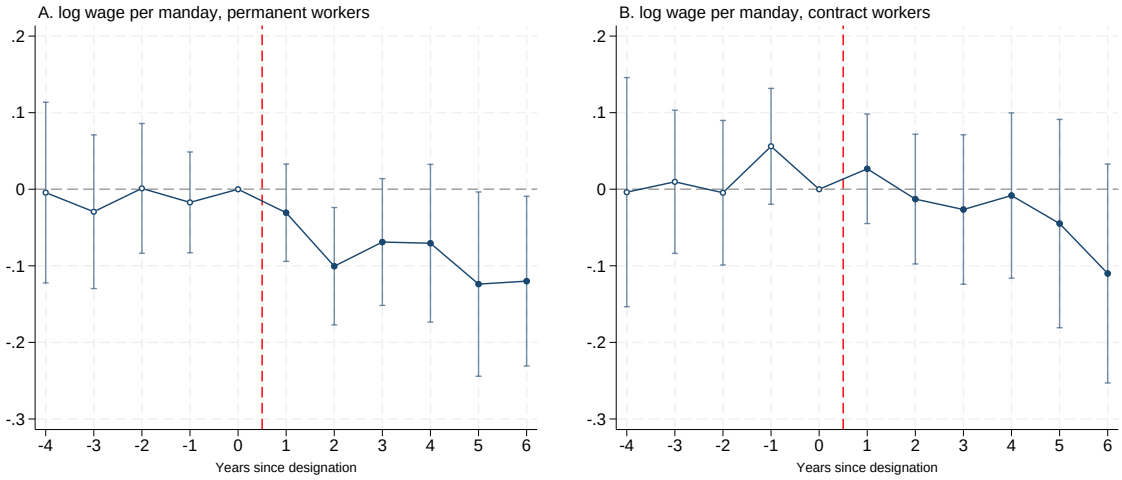


Figure 10: Wages of Permanent and Contract Workers

Notes: 397 gazette-matched designated plants (Tier A+B); the outcome is Block E wages over mandays, trimmed at the 1st and 99th percentiles. The y axis is the log outcome: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation. Standard errors are clustered by plant. Average effects over years 1–6: permanent workers −0.069 (0.032), a 7% decline; contract workers −0.018 (0.035), a 2% decline.

estimate of abatement. Figure 11 splits designated plants by position. Plants that ended short of their targets and had to buy certificates cut the permanent wage 12% (−0.122, s.e.

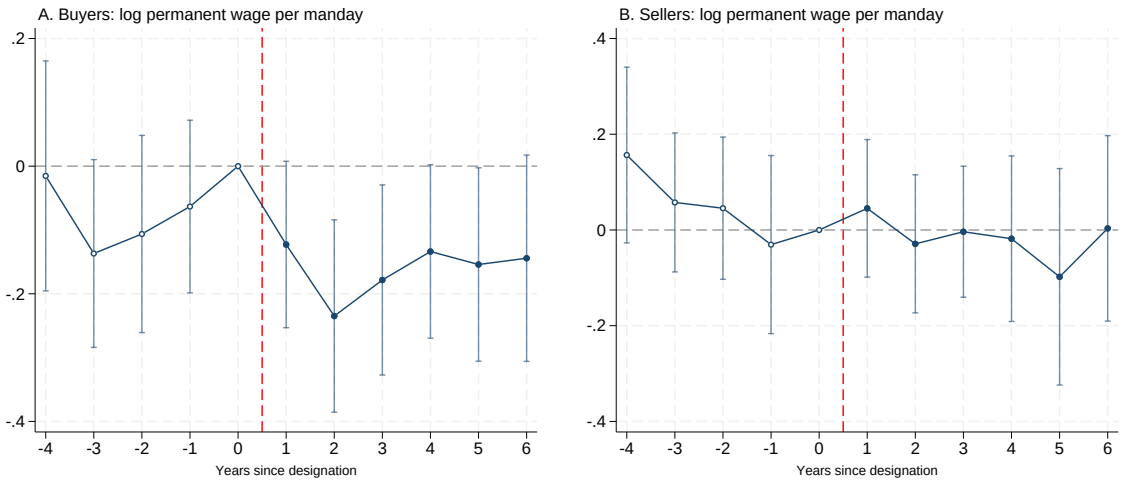


Figure 11: Permanent Wages by Certificate Position

Notes: Designated plants split by certificate position, each group against all not-yet-designated plants; the position is audited and predetermined, BEE's Cycle II baseline against the Cycle I target from the gazette. The y axis is the log permanent wage per manday: de Chaisemartin and D'Haultfœuille (2026) coefficients with 95% intervals. The x axis is years since designation. Standard errors are clustered by plant. Average effects over years 1–6: buyers −0.122 (0.042), a 12% decline; sellers −0.011 (0.052), a 1% decline.

0.042); plants that over-complied and sold cut 1% (−0.011, s.e. 0.052). The dose is the compliance cost, and the response is in the bargained wage.

6 Model

The model has two jobs: to explain the mechanism behind these facts, and to be written in the language of Tombe and Winter (2015) and Klenow et al. (2025), so the comparison with settings where abatement policy *does* misallocate is exact.

6.1 The plant

Demand. A single sector with monopolistic competition, containing the designated set $\mathcal{D}$ and the rest. Output is a CES aggregate of the plants' quantities, which hands each plant a downward-sloping demand curve:

$$Y = \left(\sum_i Q_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \qquad \Longrightarrow \qquad P_i = Q_i^{-1/\sigma} Y^{1/\sigma}, \qquad MR_i = \tfrac{\sigma-1}{\sigma} P_i. \tag{M1}$$

CES demand gives that for every plant, price is a constant markup $\frac{\sigma}{\sigma-1}$ over marginal cost: there are profits, the object Section 6.7 divides. Input prices are given to the plant: R for

capital, $\bar{w}$ for labour, P^M for the materials composite, P^E for the fuel bundle (per toe).

Technology. The production function follows Klenow, Pastén and Ruane (2025): Cobb-Douglas with plant-specific exponents, so plants can differ, particularly in their fuel intensity:

$$Q_i = A_i\big(K_i^{\alpha} L_i^{1-\alpha}\big)^{\gamma_i} M_i^{\eta_i} E_i^{1-\gamma_i-\eta_i}. \tag{M1a}$$

That heterogeneity is what justifies the existence of a policy with plant-specific intensity targets; technologically it can arise from plants using wet versus dry kilns, or captive versus grid power sources.

Labour. Labour is composed of permanent and contract workers, perfect substitutes in L_i:

$$L_i = \bar{L}_i^{p} + L_i^{c}. \tag{M1b}$$

We take the plant-level number of permanent workers $\bar{L}_i^{p}$ as fixed within the horizon; the Contract Labour Act (1970) specifies that firms keep the core team as permanent workers. Workers are paid the market wage $\bar{w}$, and contract workers are the margin; once the firm earns its profit, it pays the permanent workers a residual claim on it, the premium over the market wage.

6.2 The policy as written

Each designated plant i is given a target for its energy per unit of output, a percentage cut from its *own* audited baseline:

$$\frac{E_i}{Q_i} \le \bar{e}_i, \qquad \bar{e}_i = (1 - r_i)\, e_{0i}, \qquad e_i \equiv \frac{E_i}{Q_i}. \tag{M2}$$

The problem. The plant maximises revenue less the input bills subject to (M2). Write the constraint as $\bar{e}_i Q_i - E_i \ge 0$ with multiplier $\lambda_i \ge 0$; it enters the Lagrangian as two terms,

$$\mathcal{L}_i = P_i Q_i - R K_i - \bar{w} L_i^{c} - w_i^{p} \bar{L}_i^{p} - P^M M_i - P^E E_i \underbrace{- \lambda_i E_i}_{\text{tax on energy}} \underbrace{+ \lambda_i \bar{e}_i Q_i}_{\text{subsidy on output}}. \tag{M3}$$

The constraint charges λ_i per unit of energy and pays $\lambda_i \bar{e}_i$ per unit of output.

6.3 The policy has no first-order effect on the plant

No trading in this section: each designated plant meets its own target exactly, and λ_i is its own shadow price. The tax enters the plant's cost as an energy price $P^E + \lambda_i$; the subsidy is per unit of output and touches no input choice.

Two steps. First step: find the cost-minimising way of producing one unit of Q_i. Second step: choose Q_i.

Step 1. Write (M1a) as $Q_i = A_i \prod_j X_j^{s_{j,i}}$, where X_j runs over K_i, L_i, M_i, E_i with prices p_j ($p_E = P^E + \lambda_i$ for energy) and the effective exponents $s_{K,i} = \alpha\gamma_i$, $s_{L,i} = (1-\alpha)\gamma_i$, $s_{M,i} = \eta_i$, $s_{E,i} = 1 - \gamma_i - \eta_i$, which sum to one. The conditional problem is

$$\min_{\{X_j\}} \sum_j p_j X_j \qquad \text{subject to} \qquad Q_i = A_i \prod_j X_j^{s_{j,i}}. \tag{M3a}$$

Write the Lagrangian of (M3a), with multiplier c_i on the constraint: it is the shadow cost of one more unit of output,

$$\mathcal{L}_i^c = \sum_j p_j X_j + c_i \Big[Q_i - A_i \prod_j X_j^{s_{j,i}} \Big]. \tag{M3b}$$

Differentiate with respect to input X_j, using the Cobb-Douglas marginal product $s_{j,i} Q_i / X_j$:

$$\frac{\partial \mathcal{L}_i^c}{\partial X_j} = p_j - c_i \frac{\partial Q_i}{\partial X_j} = 0, \qquad \frac{\partial Q_i}{\partial X_j} = s_{j,i} \frac{Q_i}{X_j} \qquad \Longrightarrow \qquad p_j = c_i \, s_{j,i} \frac{Q_i}{X_j}. \tag{M3c}$$

$$X_j^* = \frac{s_{j,i} \, c_i Q_i}{p_j} : \qquad E_i^* = \frac{s_{E,i} \, c_i Q_i}{P^E + \lambda_i}, \qquad M_i^* = \frac{s_{M,i} \, c_i Q_i}{P^M}, \qquad K_i^* = \frac{s_{K,i} \, c_i Q_i}{R}, \qquad L_i^* = \frac{s_{L,i} \, c_i Q_i}{\bar{w}}. \tag{M3d}$$

$$Q_i = A_i \, (c_i Q_i) \prod_j \Big(\frac{s_{j,i}}{p_j} \Big)^{s_{j,i}} \qquad \Longrightarrow \qquad c_i = \frac{1}{A_i} \prod_j \Big(\frac{p_j}{s_{j,i}} \Big)^{s_{j,i}}. \tag{M3e}$$

Sum the bills across inputs, substituting the demands (M3d): the price cancels input by input, and the shares sum to one,

$$\sum_j p_j X_j^* = \sum_j p_j \, \frac{s_{j,i} \, c_i Q_i}{p_j} = \Big(\sum_j s_{j,i} \Big) c_i Q_i = c_i \, Q_i : \tag{M3f}$$

total cost is $c_i Q_i$, so the multiplier c_i is the unit cost.

With the energy price $P^E + \lambda_i$, write out the four factors of (M3e):

$$c_i(\lambda) = \frac{1}{A_i} \Big(\frac{R}{s_{K,i}} \Big)^{s_{K,i}} \Big(\frac{\bar{w}}{s_{L,i}} \Big)^{s_{L,i}} \Big(\frac{P^M}{s_{M,i}} \Big)^{s_{M,i}} \Big(\frac{P^E + \lambda}{s_{E,i}} \Big)^{s_{E,i}} = B_i \, (P^E + \lambda)^{s_{E,i}}, \tag{M4}$$

where B_i collects every factor that does not contain λ: only the last factor moves with the policy.

Divide (M4) by itself at $\lambda = 0$: $c_i(M0)$ is the pre-policy unit cost, and B_i cancels,

$$\frac{c_i(\lambda)}{c_i(M0)} = \Big(\frac{P^E + \lambda}{P^E}\Big)^{s_{E,i}} = (1+t)^{s_{E,i}}, \qquad t \equiv \frac{\lambda}{P^E}. \tag{M4a}$$

For small t, a first-order Taylor expansion of (M4a) around $t = 0$ gives

$$\frac{c_i(\lambda)}{c_i(M0)} \;\approx\; 1 + s_{E,i}\, t :$$

the shadow cost rises by the energy share times the tax. By Shephard's lemma the intensity is the derivative of the unit cost in the energy price;[4] evaluating it with (M4),

$$e_i(\lambda) = \frac{\partial c_i(\lambda)}{\partial(P^E + \lambda)} = \frac{s_{E,i}\, c_i(\lambda)}{P^E + \lambda}, \qquad e_{0i} = \frac{s_{E,i}\, c_i(M0)}{P^E} \;\text{ at } \lambda = 0. \tag{M4b}$$

Divide the two: $s_{E,i}$ cancels, and what remains is the cost ratio (M4a) times a price ratio,

$$\frac{e_i(\lambda)}{e_{0i}} = \frac{s_{E,i}\, c_i(\lambda)/(P^E + \lambda)}{s_{E,i}\, c_i(M0)/P^E} = \underbrace{\frac{c_i(\lambda)}{c_i(M0)}}_{(1+t)^{s_{E,i}}} \cdot \underbrace{\frac{P^E}{P^E + \lambda}}_{(1+t)^{-1}} \qquad \Longrightarrow \qquad e_i(\lambda) = e_{0i}\,(1+t)^{-(1-s_{E,i})}. \tag{M4c}$$

The plant prices off the *net* unit cost, the shadow cost less the subsidy $\lambda_i \bar{e}_i$ per unit of output from the Lagrangian (M3):

$$\tilde{c}_i = c_i(\lambda_i) - \lambda_i \bar{e}_i. \tag{M5}$$

Since λ_i enters (M4) only through the price $P^E + \lambda_i$, Shephard gives $dc_i/d\lambda_i = e_i(\lambda_i)$, the intensity the plant chooses when energy costs $P^E + \lambda_i$; so the derivative of the net cost in the multiplier is exactly the gap between the plant's chosen intensity and its target:

$$\frac{d\tilde{c}_i}{d\lambda_i} = e_i(\lambda_i) - \bar{e}_i. \tag{M5a}$$

At the target (no trading needed) $e_i = \bar{e}_i$ and the derivative is zero: the tax the plant pays equals the subsidy it receives, because the subsidy is scaled by the plant's *own* target.

[4] The total cost function is $C(Q_i, \vec{p}) = \min_{\{X_j\}} \sum_j p_j X_j$ subject to (M1a), and Shephard's lemma is $\partial C(Q_i, \vec{p})/\partial p_E = E_i^*(Q_i, \vec{p})$. Here the energy price is $p_E = P^E + \lambda$ and, by (M3f), $C(Q_i, \vec{p}) = c_i(\lambda)\, Q_i$, so $Q_i\, \partial c_i(\lambda)/\partial(P^E + \lambda) = E_i^*$, i.e. $\partial c_i(\lambda)/\partial(P^E + \lambda) = E_i^*/Q_i = e_i(\lambda)$.

Measured revenue productivity:

$$TFPR_i \equiv \frac{P_i Q_i}{RK_i + \bar{w} L_i^c + w_i^p \bar{L}_i^p + P^M M_i + P^E E_i}.$$

The bill is $c_i(\lambda_i)Q_i - \lambda_i E_i$ by (M3f); at the target $E_i = \bar{e}_i Q_i$ (M2), so the bill is $\big(c_i(\lambda_i) - \lambda_i \bar{e}_i\big)Q_i = \tilde{c}_i Q_i$ by (M5). With marginal revenue (M1) equal to the net marginal cost, $P_i = \frac{\sigma}{\sigma-1}\tilde{c}_i$; divide:

$$TFPR_i = \frac{\frac{\sigma}{\sigma-1}\,\tilde{c}_i Q_i}{\tilde{c}_i Q_i} = \frac{\sigma}{\sigma-1} \quad \forall i, \text{ before and after, exactly.} \tag{M6}$$

The policy does not create any new distortion.

6.4 Abatement cost: second order approximation

The cost. Step 1 solved the plant's problem for arbitrary λ. From (M5a) and the fundamental theorem of calculus,

$$\Delta\tilde{c}_i = \int_0^{\lambda_i^*} \big(e_i(u) - \bar{e}_i\big)\, du \;\approx\; \tfrac{1}{2}\,\lambda_i^*\, r_i\, e_{0i}. \tag{M7}$$

The shadow price. The target pins λ_i^*: set $e_i(\lambda_i^*) = \bar{e}_i = (1-r_i)\,e_{0i}$, from (M2), in (M4c),

$$\begin{aligned}
(1+t_i^*)^{-(1-s_{E,i})} &= 1 - r_i && \text{the target condition}\\
-(1-s_{E,i})\,\ln(1+t_i^*) &= \ln(1-r_i) && \text{take logs of both sides}\\
-(1-s_{E,i})\,t_i^* &\approx\; -r_i && \ln(1+x)\approx x,\ \text{with } x = t_i^* \text{ and } x = -r_i\\
(1-s_{E,i})\,t_i^* &\approx\; r_i && \text{multiply by } -1
\end{aligned}$$

$$t_i^* \approx \frac{r_i}{1-s_{E,i}}, \qquad \lambda_i^* = t_i^* P^E \approx \frac{P^E\, r_i}{1-s_{E,i}}. \tag{M7a}$$

The last step, $\lambda_i^* = t_i^* P^E$, is the definition of t in (M4a), converting the rate back into the price units of (M7).

In shares of the bill. Substituting back into (M7):

$$\Delta\tilde{c}_i \;\approx\; \tfrac{1}{2}\,\frac{P^E r_i}{1-s_{E,i}}\, r_i\, e_{0i} \;=\; \tfrac{1}{2}\,\frac{P^E e_{0i}}{1-s_{E,i}}\, r_i^2.$$

Next, replace $P^E e_{0i}$ from (M4b) at $\lambda = 0$:

$$\Delta\tilde{c}_i \;\approx\; \tfrac{1}{2}\,\frac{s_{E,i}\,c_i(M0)}{1 - s_{E,i}}\,r_i^2.$$

Finally define $\Phi_i \equiv \Delta\tilde{c}_i\,Q_i$, the plant's total cost of compliance, and $C_i = c_i(M0)Q_i$, the pre-policy bill, from (M3f) at $\lambda = 0$; Q_i cancels in the ratio, and dividing the last display by $c_i(M0)$:

$$\frac{\Phi_i}{C_i} = \frac{\Delta\tilde{c}_i}{c_i(M0)} \;\approx\; \frac{1}{2}\,\frac{s_{E,i}\,r_i^2}{1 - s_{E,i}}. \tag{M7b}$$

6.5 Exact abatement cost using Sato-Vartia weights

(M7b) kept the leading term of the net cost change $\Delta\tilde{c}_i$ in (M7), relative to $c_i(M0)$; the same object can be computed with no approximation, straight from the accounts.

The gross cost rise. The object we want is $c_i(\lambda_i^*)/c_i(M0)$: how much dearer one unit is at the target than with no policy, now without assuming the Cobb-Douglas form. The strategy: find the derivative of $\ln c_i$ in the energy price, which holds for any technology, then integrate it from P^E to $P^E(1 + t_i^*)$. Step by step:

$$\begin{aligned}
\frac{\partial \ln c_i}{\partial \ln p_E} &= \frac{p_E}{c_i}\,\frac{\partial c_i}{\partial p_E} && \text{chain rule: } d\ln c = dc/c,\; d\ln p_E = dp_E/p_E \\
&= \frac{p_E\,e_i}{c_i} && \text{Shephard's lemma (M4b): } \partial c_i/\partial p_E = e_i \\
&= s_E(p_E) && \text{definition: energy spending over total cost, the share ((M3b) is its Cobb-Douglas case}
\end{aligned}$$

We work in logs because we will use Sato-Vartia in the next step. Integrating:

$$\ln\frac{c_i(\lambda_i^*)}{c_i(M0)} = \int_{P^E}^{P^E(1+t_i^*)} s_E(p)\,d\ln p_E. \tag{M7c}$$

Line by line:

$$\begin{aligned}
\int_{P^E}^{P^E(1+t_i^*)} s_E(p)\,d\ln p_E &= \bar{s}\int_{P^E}^{P^E(1+t_i^*)} d\ln p_E && \text{mean value theorem: } \bar{s} \text{ an average of } s_E \text{ on the pa} \\
&= \bar{s}\left[\ln\left(P^E(1+t_i^*)\right) - \ln P^E\right] && \text{evaluate the integral} \\
&= \bar{s}\,\ln(1+t_i^*) && \text{log ratio of the endpoints: } P^E \text{ cancels}
\end{aligned}$$

By Sato (1976) and Vartia (1976), for any CES technology this average value $\bar{s}$ is exactly

the logarithmic mean of the endpoints,

$$w_{E,i} \equiv \frac{s^1_{E,i} - s^0_{E,i}}{\ln s^1_{E,i} - \ln s^0_{E,i}}\,.$$

So, line by line:

$$\begin{aligned}
\ln \frac{c_i(\lambda_i^*)}{c_i(M0)} &= w_{E,i}\,\ln(1+t_i^*) && \text{substitute } \bar{s} = w_{E,i} \text{ into (M7c)} \\
\frac{c_i(\lambda_i^*)}{c_i(M0)} &= (1+t_i^*)^{w_{E,i}} && \text{exponentiate both sides: } e^{a\ln b} = b^a \\
\frac{c_i(\lambda_i^*) - c_i(M0)}{c_i(M0)} &= (1+t_i^*)^{w_{E,i}} - 1 && \text{subtract 1.}
\end{aligned} \tag{M7d}$$

Less the subsidy. The plant also receives the output-side subsidy $\lambda_i^* \bar{e}_i$ per unit. Normalise by baseline unit cost; substitute $\lambda_i^* = P^E t_i^*$ from (M4a) and $\bar{e}_i = (1-r_i)\,e_{0i}$ from (M2), and recognise the baseline energy cost share $s^0_{E,i} = P^E e_{0i}/c_i(M0)$ from (M4b):

$$\frac{\lambda_i^* \bar{e}_i}{c_i(M0)} = t_i^*\,(1-r_i)\,\frac{P^E e_{0i}}{c_i(M0)} = s^0_{E,i}\,t_i^*\,(1-r_i).$$

The net cost. Together,

$$\frac{\Delta \tilde{c}_i}{c_i(M0)} = \underbrace{(1+t_i^*)^{w_{E,i}} - 1}_{\text{gross cost rise}} - \underbrace{s^0_{E,i}\,t_i^*\,(1-r_i)}_{\text{subsidy}}. \tag{M7e}$$

Under Cobb-Douglas the share does not move ((M3b)): $s^1_{E,i} = s^0_{E,i}$, and the log-mean collapses to the common value. Write $s^1_{E,i} = s^0_{E,i}(1+\varepsilon)$ and let $\varepsilon \to 0$:

$$w_{E,i} = \frac{s^0_{E,i}(1+\varepsilon) - s^0_{E,i}}{\ln\big(s^0_{E,i}(1+\varepsilon)\big) - \ln s^0_{E,i}} = \frac{s^0_{E,i}\,\varepsilon}{\ln(1+\varepsilon)} \xrightarrow{\varepsilon \to 0} s^0_{E,i}\,,$$

using $\ln(1+\varepsilon) \approx \varepsilon$ once more; so $w_{E,i} = s^0_{E,i}$ and (M7e) is the Cobb-Douglas closed form.

6.6 The cost in numbers

For the typical designated plant the policy costs a few hundredths of a percent of the bill. The energy cost share is spending on fuels and purchased electricity over the total input bill,

$$s^0_{E,i} = \frac{P^E E_i}{RK_i + \bar{w} L_i^c + w_i^p \bar{L}_i^p + P^M M_i + P^E E_i}\,,$$

measured in the ASI over the pre-policy years 2008–11. The median across designated plants is 0.16. Take the mean gazette cut, $r = 0.05$. From (M7a), the shadow tax is $t^* = 0.05/(1 - 0.16) = 0.060$. From (M7d), the gross cost rise is $(1.060)^{0.16} - 1 = 0.93\%$ of cost. The subsidy is $s_E^0\, t^*(1 - r) = 0.16 \times 0.060 \times 0.95 = 0.90\%$ of cost. From (M7e), the net cost is $0.93\% - 0.90\% = 0.025\%$ of the bill, against 0.024% from the second-order approximation (M7b). Deep in the tail of the targets, $r = 0.17$, the same four lines give $t^* = 0.202$, a gross rise of 2.99%, a subsidy of 2.69%, and a net cost of 0.31% ((M7b): 0.28%). This is aligned with the second-order approximation (M7b), and with the fact that most plants do not trade: the wedge is the plant's own shadow price t_i^*, not a market price (Section 6.8 adds the market price for the plants that do trade).

6.7 How the cost is paid

Where the money goes. Start from the conditional input demands (M3d), at the tax-inclusive prices: $X_j^* = s_{j,i}\, c_i(\lambda)\, Q_i/p_j$, with $p_E = P^E + \lambda$ for energy and market prices for the rest. Two facts: Q_i is fixed to first order (Section 6.3), and the non-energy prices P^M, R, $\bar{w}$ do not change. So for materials, capital and labour the only moving part is $c_i(\lambda)$, whose change is given by (M4a). For energy the own price rises as well, and the two effects work in opposite directions:

$$\frac{M_i^1}{M_i^0} = \frac{c_i(\lambda_i^*)}{c_i(M0)} = (1 + t_i^*)^{s_{E,i}}, \qquad \frac{E_i^1}{E_i^0} = \frac{(1 + t_i^*)^{s_{E,i}}}{1 + t_i^*} = (1 + t_i^*)^{s_{E,i} - 1}.$$

Take logs; the argument for M_i is identical for K_i and L_i:

$$\Delta \ln M_i = \Delta \ln K_i = \Delta \ln L_i = s_{E,i} \ln(1 + t_i^*), \qquad \Delta \ln E_i = -(1 - s_{E,i}) \ln(1 + t_i^*) : \quad \text{(M8)}$$

energy falls while every other input rises, all by the same log amount.

Equal percentages are not equal rupees. Under Cobb-Douglas baseline spending on input j is its share of the bill, $p_j X_j = s_{j,i}\, c_i Q_i$ (M3b), so the spending increments are proportional to the shares: input j takes the fraction $s_{j,i}/(1 - s_{E,i})$ of the offsetting outlay,

$$\underbrace{\frac{\eta_i}{1 - s_{E,i}}}_{\text{materials} \approx 0.71} \qquad \underbrace{\frac{s_{K,i}}{1 - s_{E,i}}}_{\text{capital} \approx 0.18} \qquad \underbrace{\frac{s_{L,i}}{1 - s_{E,i}}}_{\text{labour} \approx 0.11}$$

at the ASI cost shares $\eta_i \approx 0.6$, $s_{K,i} \approx 0.15$, $s_{L,i} \approx 0.09$, s

(M9)

The event studies of Section 5 show the ordering the shares predict: materials rise 12%, capital 6% and employment 3%. The materials response is larger than the equal-percentage prediction of (M8) and tilted toward materials, the direction the shares imply; the excess is

the technique change that the Peter-Ruane extension below picks up.

The claims. The markup rent is $S_i = R_i/\sigma$ with $R_i \equiv P_i Q_i$. Before the policy it is split between the owners' claim Π^o_{i0} and the premium pool paid to the fixed permanent stock,

$$w^p_{i0} = \bar{w} + \frac{\Pi^w_{i0}}{\bar{L}^p_i}, \qquad w^c_i = \bar{w}, \qquad \Pi^w_{i0} = S_{i0} - \Pi^o_{i0}. \tag{M10}$$

Within the horizon the settlement holds the owners' claim at its pre-policy level, $\Pi^o_i = \Pi^o_{i0}$: the owners keep the profit they had, and the premium pool is the residual claim on the surplus. The whole abatement cost passes through to the premium,

$$\Delta\Pi^w_i = \Delta S_i = -\,\Phi_i, \qquad \Delta w^p_i = -\frac{\Phi_i}{\bar{L}^p_i}, \qquad \Delta w^c_i = 0. \tag{M11}$$

The abatement cost is cut from the wage bonus of the permanent workers. Because $\bar{L}^p_i$ is fixed the premium is inframarginal: no first-order condition in (M3) contains it, so wages move and no quantity does. The predictions are the results: the permanent wage falls and the contract wage does not; measured profit rates are flat; and since Φ_i contains the certificate bill, the cut is steepest where certificates were bought (buyers -12%, sellers -1%).

The size of the observed cut places the settlement between two benchmarks. At $\Phi_i/C_i = 0.003$, proportional sharing of the cost across all claims on the plant would predict a wage change of about -0.6%, while the full residual claim in (M11) predicts about -19%. The estimates, -7% overall and -12% at buyers, lie between the two and much closer to the residual claim: the settlement charges shocks to the premium far more than proportionally.

6.8 The trading extension: one certificate price across plants

The market. Certificates make the target tradable: a plant short of its target buys, a plant beyond it sells, and one price λ clears the market across the designated plants:

$$\sum_{i \in \mathcal{D}} \left(\bar{e}_i Q_i - E_i \right) = 0. \tag{M13}$$

What changes for the plant. The market price λ replaces the plant's own shadow price λ^*_i: every plant abates to the same marginal cost, stopping at $e_i(\lambda)$ from (M4c) rather than at its own target. The derivative (M5a) is no longer zero plant by plant; it is the plant's certificate position, positive for a buyer ($\lambda^*_i > \lambda$), negative for a seller ($\lambda^*_i < \lambda$). The cost of

the policy splits in two:

$$\Delta\tilde{c}_i = \underbrace{c_i(\lambda) - c_i(M0) - \lambda\, e_i(\lambda)}_{\text{abatement cost, second order}} + \underbrace{\lambda\big(e_i(\lambda) - \bar{e}_i\big)}_{\text{certificate bill } B_i\text{, a transfer}}, \qquad \sum_{i\in\mathcal{D}} B_i Q_i = 0 \text{ by (M13).} \tag{M14}$$

What survives of the proposition. The bill is a transfer between designated plants, zero in aggregate; measured $TFPR_i$ moves only through it, $\Delta \ln TFPR_i \approx s_{E,i}\, t\, \nu_i$ with $\nu_i \equiv (e_i(\lambda) - \bar{e}_i)/e_{0i}$: positive for buyers, negative for sellers, zero on average across the scheme. Trading equalises marginal abatement cost, which is cost-effectiveness; allocative efficiency is untouched on average. The position ν_i is the dose the buyer/seller results read: Φ_i in (M11) contains B_i, so the wage cut is steepest where certificates were bought.

The numbers. At the observed certificate-price wedges, $t \approx 0.1$–0.2, and a typical buyer's position $\nu_i \approx 0.17$ (the audited Cycle II baseline against the Cycle I target), the bill is

$$\frac{B_i}{c_i(M0)} = s^0_{E,i}\, t\, \nu_i \approx 0.16 \times 0.2 \times 0.17 \approx 0.5\% \text{ of cost.}$$

Adding the abatement cost at the market price, a buyer's total is $\Phi_i/C_i \approx 0.9\%$, against 0.3% or less for a plant at its target and roughly zero for a seller, whose bill is revenue. The TFPR movement $s_{E,i}\, t\, \nu_i$ is +0.6% for the typical buyer and negative for sellers: zero on average, and far inside the (0.014) standard error of the TFPR estimate. Through (M11), the buyer's larger Φ_i is the predicted wage gradient; the estimates give −12% at buyers against −1% at sellers.

6.9 The elasticity from the certificate price

The nest. Replace (M1a) with Peter and Ruane's nested CES, the plant's TFP outside:

$$Q_i = A_i\, \mathrm{CES}_\varepsilon\big(N_i,\, X_i\big), \qquad N_i = K_i^\alpha L_i^{1-\alpha}, \qquad X_i = \mathrm{CES}_\theta\big(E_i,\, M_i\big), \tag{M15}$$

ε between value added and the energy-materials bundle, θ inside the bundle; Cobb-Douglas is $\theta = \varepsilon = 1$. Nothing in Section 6.3 changes: (M5a) is an envelope statement, so the cancellation and (M6) are exact for any θ, ε.

What changes. The intensity now falls along two margins, less energy inside the bundle (θ) and a smaller bundle relative to value added (ε), with combined elasticity

$$e_i(\lambda) = e_{0i}\,(1+t)^{-\psi_i}, \qquad \psi_i \equiv \theta\, s^X_{M,i} + \varepsilon\, s_{N,i}\, s^X_{E,i} \qquad \text{(replacing (M4c))}, \tag{M16}$$

where $s^X_{E,i}, s^X_{M,i}$ are the cost shares inside the bundle and $s_{N,i}$ the value-added share ($\psi_i =$

$1 - s_{E,i}$ at $\theta = \varepsilon = 1$). ψ_i replaces $1 - s_{E,i}$ in (M7b): $\Phi_i/C_i \approx \frac{1}{2}\, s_{E,i} r_i^2/\psi_i$. At their estimates ($\theta = 1.00$, $\varepsilon = 0.79$) the number barely moves; at $\theta \approx 3$ the abatement cost is roughly a third of the Cobb-Douglas figure.

The elasticity. Relative demand inside the bundle gives $\Delta \ln(M_i/E_i) = \theta \ln(1+t)$. The certificate price is an observed, audited wedge on energy, so θ is identified from a policy experiment rather than from cross-sectional price variation:

$$\hat{\theta} = \frac{\Delta \ln(M/E)}{\ln(1+t)} = \frac{0.25}{\ln(1+t)} \;\approx\; 1.4\text{–}3 \;\text{ at observed certificate-price wedges } t \approx 0.08\text{–}0.2, \tag{M17}$$

well above one at any certificate price in the observed range, against their economy-wide 1.0.

Substitution or technique. What a large θ is made of is visible at these plants: blended cement, recycled fibre, purchased alumina; recipe changes, not slides along a smooth isoquant. In Peter-Ruane's language it is substitution; in the engineering it is technique change; the product-mix evidence (the blended share of cement sales rises) is the elasticity's identity. For their aggregate question the direction matters: at hard-to-abate plants the energy-materials margin is more elastic than their economy-wide estimate, so intensity targets are cheaper than their calibration implies.

7 Conclusion

How do firms pay for energy abatement? I examine India's PAT scheme, a plant-specific tradable energy-intensity standard, using digitised gazette targets matched to a 26-year ASI factory panel. Three results organise the answer. The regulated energy-output ratio falls 27% after designation, three times the cumulative mandate, with output rising, energy falling, materials rising, and employment and capital rising by less. Profits and labor productivity are unchanged. Permanent workers' wages fall 7% while contract wages at the same plants are flat, with the cut steepest at plants that had to buy certificates.

A model of the plant's compliance problem explains this pattern through a single cancellation. The tradable own-baseline intensity target is an energy tax plus an output subsidy: the two flows cancel at first order, so no distortion opens across plants and nothing moves in TFPR; the second-order abatement cost, 0.03% to 0.3% of the bill, is cut from the premium the plant's wage settlement pays its fixed permanent workforce. The cost of the policy is real but small, and it lands on the residual claimant inside the plant.

The lesson concerns the design of the instrument, and India's new carbon market has inherited that design. The Carbon Credit Trading Scheme carries over PAT's plant-level, own-baseline intensity-target architecture and its list of plants. On this evidence, that ar-

chitecture abates without misallocating and without denting profits or productivity; its cost is second order and passes through rent sharing to workers; and if benchmarks again underguess how cheap abatement is, the certificate price will again fall to its floor.

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