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The impact of energy efficiency regulation on employment in India's pulp and paper industry

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Abstract
This paper examines the employment effects of India's Perform, Achieve, and Trade (PAT) scheme, a market-based energy efficiency regulation, focusing on the pulp and paper sector. While existing research on PAT has primarily emphasized energy savings and cost efficiency, its labor market implications remain largely unexplored, particularly in labor-abundant developing economies. Using firm-level panel data from 2002 to 2019 and a difference-in-differences framework with firm- and year-fixed effects, we estimate the causal impact of PAT participation on employment outcomes. The results indicate that PAT participation is associated with a statistically significant decline in employment, averaging around 13% relative to non-participating firms. To interpret these findings, we draw on the framework of Morgenstern, Pizer, and Shih, which highlights cost, factor substitution, and demand channels as key mechanisms through which environmental regulation affects labor demand. Consistent with this framework, the analysis suggests that PAT-induced efficiency improvements reduce production costs and affect sales dynamics, contributing to lower employment levels. These findings highlight potential trade-offs between environmental regulation and employment in the short run. They underscore the importance of complementary policies, such as skill development programs, labor-supportive incentives, and employment-sensitive policy design, to ensure a more balanced transition toward energy efficiency in developing economies.

Keywords Pulp and paper, Employment, Energy efficiency, PAT scheme, Labor outcome

1 Introduction

The transition toward low-carbon growth has become a central policy challenge for emerging economies. In energy-intensive industries, such as pulp and paper, policy interventions to improve energy efficiency raise important concerns about their broader implications for firm performance and labor markets. While much of the literature emphasizes the impact of environmental regulation on productivity, costs, and emissions reduction [2, 23, 35], the consequences for employment remain less understood.

This gap is particularly salient for developing economies, where industrial employment is critical in sustaining livelihoods and stringent environmental policies are often perceived as potentially labor-displacing.

India's Perform, Achieve, and Trade (PAT) scheme, launched in 2012, represents one of the global South's most ambitious market-based energy efficiency programs. The scheme targets designated energy-intensive firms with binding efficiency benchmarks while allowing flexibility through tradable certificates. Existing research on PAT has primarily analyzed its effectiveness in reducing energy intensity and compliance costs [16, 31]. However, its employment effects remain unexplored, particularly in industries like pulp and paper, where energy costs are substantial and technological upgrading is central—understanding whether the PAT scheme induced labor displacement or created opportunities for skill upgrading is crucial for designing "just" energy transitions in India.

Despite a growing body of work on the economic impacts of environmental regulation, existing evidence on labor-market effects remains inconclusive and is largely confined to developed countries. In particular, there is limited firm-level evidence on how market-based energy efficiency policies affect employment outcomes in developing economies. This gap is especially important in labor-abundant countries such as India, where concerns about job losses may constrain the implementation of climate policies. Moreover, policies such as the Perform, Achieve and Trade (PAT) scheme differ from traditional command-and-control regulations, and their labor-market implications remain underexplored.

To address this gap, this paper examines the effects of the PAT scheme on the labor market in India's pulp and paper sector. Using a difference-in-differences (DID) framework with firm- and year-fixed effects, we compare employment trajectories of firms covered under PAT to those outside the scheme between 2002 and 2019. Our analysis reveals that, on average, PAT adoption is associated with a decline in employment, though the magnitude varies across firm types and adjustment channels. To interpret these results, we draw on the Morgenstern, Pizer, and Shih [30] framework, which decomposes employment impacts into cost, factor-shift, and demand effects. Mechanism analysis suggests that cost reductions, shifts toward more capital-intensive production, and changes in sales dynamics account for the observed employment responses. This framework provides a useful lens to interpret how energy efficiency policies may influence labor demand at the firm level.

This paper makes two main contributions to the literature by providing, to the best of the authors' knowledge, the first firm-level evidence on the employment effects of India's PAT scheme in the pulp and paper sector. First, it adds to the literature on the distributional consequences of environmental regulation by focusing on employment, an outcome of particular policy relevance in labor-abundant economies. Second, it extends the MPS framework to a developing-country context, highlighting the mechanisms by which energy efficiency policies reshape firm behavior. In doing so, the paper speaks to broader debates on whether environmental regulation in emerging economies can align climate and employment objectives.

The remainder of the paper is organized as follows. Section 2 provides the institutional background and an overview of the Indian pulp and paper sector. Section 3 reviews the relevant literature. Section 4 describes the methodology, data, and variables. Section 5 presents the main results, followed by robustness checks and mechanism analysis. Finally, Sect. 6 concludes and presents policy recommendations.

2 Institutional background

2.1 The PAT scheme

The Perform, Achieve and Trade Scheme was introduced in 2012 by the Bureau of Energy Efficiency (BEE) as part of the National Mission for Enhanced Energy Efficiency (NMEEE), one of the eight national missions outlined in the National Action Plan on Climate Change (NAPCC) in 2008. It is India's first market-based energy efficiency trading program. A regulatory instrument, the PAT scheme aims to reduce the specific energy consumption (SEC) of energy-intensive industries listed in the Energy Conservation Act, 2001 [11]. Given India's dual objectives of industrial growth and emissions reduction, PAT represents a cornerstone of the country's green industrial policy.

The identification of firms under the PAT scheme follows a predefined institutional process. Sectoral energy-saving targets are determined on a pro rata basis relative to the energy consumption of all sectors included in the policy. Subsequently, sub-sectoral targets are set based on the energy consumption of various groups within the sector. Finally, industrial units are selected as "designated consumers" (DCs), based on the minimum threshold energy consumption criteria rolled out by the BEE for each sector, which is 20,000 million tonnes of oil equivalent (toe) for the pulp and paper sector [11]. In this sense, units that meet the eligibility criteria can be considered potential participants. At the same time, those formally notified by the BEE constitute the final set of regulated entities for each cycle. Individual DC baselines and targets are calculated based on the relative specific energy consumption (SEC) of a DC. Through a gate-to-gate concept of a plant's boundary, the energy sources used and the output produced are taken into account to derive the SEC. The selection is therefore based on pre-determined technical and energy-intensity criteria rather than firm-level outcomes such as employment or productivity. This institutional feature is important for the empirical strategy, as it reduces concerns that participation is driven by contemporaneous firm performance, thereby supporting the plausibility of the identification approach.

The PAT scheme is implemented in three-year cycles. The first two cycles were implemented in succession. With the third cycle, the scheme was notified on a rolling basis, allowing for the addition of more DCs each year. So far, the BEE has rolled out seven cycles. To observe the energy-saving targets the DCs achieve, BEE employs energy auditors to monitor and verify the process. It also has a market-based mechanism to enhance cost-effectiveness by issuing energy-saving certificates (ESCs) to DCs that report excess energy savings [9]. DCs purchase ESCerts that did not meet their assigned energy-saving targets. The ESCerts are traded on platforms such as the Indian Energy Exchange (IEX) and Power Exchange India Limited (PXIL). In cycle I, there was no demand for ESCerts in the pulp and paper sector. From cycle II, demand emerged in the sector [10].

2.2 The pulp and paper sector

The pulp and paper industry is one of India's most critical sectors, contributing around 8,000 crores to the exchequer and providing employment to 2.5 million people, directly and indirectly [12]. With a 6% CAGR, the pulp and paper industry is highly fragmented, with more than 600 small and medium-sized enterprises [17]. Approximately 68% of the mills use fiber-based recycled materials, 23% use wood-based materials, and 9% use agro-based raw materials [6]. This sector is energy-intensive and the third-largest water user, raising environmental concerns. It causes pollution in agricultural fields and water bodies, producing significant amounts of toxic waste [24]. Energy is one of the most critical parameters in this sector, leading to rising input costs [12].

The pulp and paper industry is embedded within a broader production network characterized by significant upstream and downstream linkages. Upstream, the sector depends on inputs such as wood, waste paper, chemicals, and energy, making it closely tied to forestry, recycling, and energy sectors. Downstream, it supplies key inputs to industries such as packaging, printing, publishing, and fast-moving consumer goods [6]. These linkages imply that technological changes induced by energy efficiency regulations, such as the PAT scheme, may not only affect production processes within firms but also influence input demand and output markets across related industries.

Implementing energy-efficient technologies is a pressing need of the hour, and the PAT scheme is a step in the right direction, which may also have a positive impact on employment. Regarding employment, Fig. 1 shows trends in the number of employees in the pulp and paper and industrial sectors.

Following an increase from 2008 to 2010, the number of employees began declining until 2015, then rose slightly after 2015, reaching a peak in 2018. For the two cycles of the PAT scheme, employment is generally declining with a moderate increase in the final phase of cycle two. This trend is generally positive in the industrial sector, with only minor dips in 2011 and 2020. In Fig. 2, wages and salaries are plotted for the pulp and paper and industrial sectors. There are ups and downs in wages and salaries, particularly in the first two PAT cycles, with a marginal overall increase, a distinct increase in 2017, and a decline around 2020. For industries, a similar trend is observed, with a decrease around the COVID-19 pandemic. A decrease in employment and an increase in wages and salaries could indicate skill upskilling in the pulp and paper sector, leading to a higher total wage bill. However, further evidence is required to ascertain this fact.

The pulp and paper industry is characterized by a heterogeneous workforce combining both skilled and unskilled labor. Production processes involve a mix of manual operations and capital-intensive machinery, with skilled workers engaged in technical and supervisory roles and semi-skilled or unskilled workers performing routine operational tasks. Industry reports indicate that energy-intensive stages of production, such as

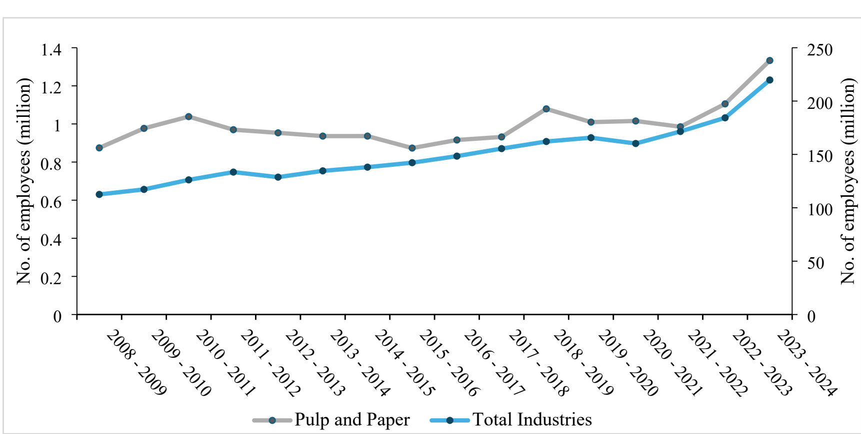

Fig. 1 Trends in the number of employees in the pulp and paper industry and in the industrial sector as a whole

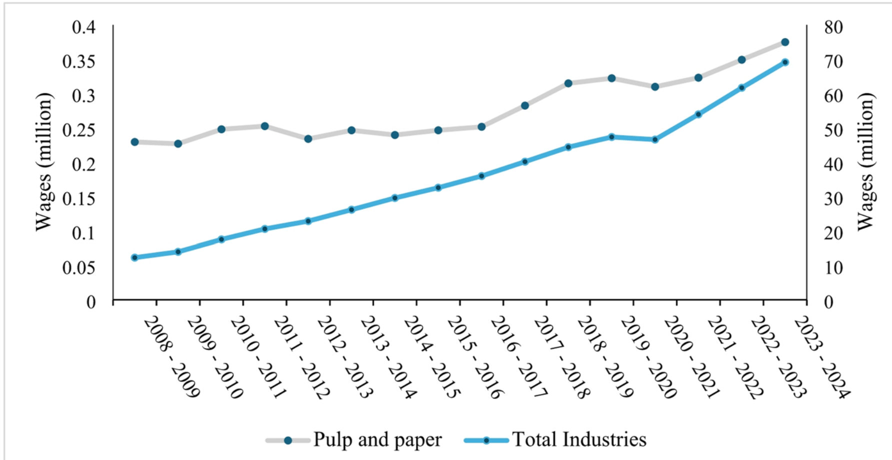

Fig. 2 Trends in wages and salaries in the pulp and paper industry and in the industrial sector as a whole

pulping and chemical processing, increasingly rely on mechanization and process optimization [6, 22]. As a result, technological upgrades and energy efficiency improvements may shift labor demand toward more skilled workers while reducing reliance on routine manual labor. While firm-level data on workforce composition are not available in the present study, this industry context is important for interpreting the employment effects of the PAT scheme.

3 Literature review

3.1 Environmental regulation and employment: theoretical perspectives

The employment implications of environmental regulation have long been a central focus of debates over the trade-off between economic growth and sustainability. Traditional economic reasoning emphasizes the cost burden of environmental policies: by imposing compliance costs, these policies can increase production expenses, reduce competitiveness in global markets, and potentially lead to job displacement in regulated sectors. This jobs-versus-environment trade-off has historically dominated policy discussions, particularly in energy- and labor-intensive industries where production costs are most sensitive to regulatory changes.

However, alternative theoretical perspectives suggest that this pessimistic view is overly simplistic. One prominent argument is advanced in the Porter Hypothesis [35], which posits that well-designed environmental regulations may induce firms to innovate, adopt cleaner technologies, and improve resource efficiency. Such innovation-driven responses may offset the direct compliance costs and improve competitiveness, generating positive or neutral employment effects. Another lens is provided by the theory of skill-biased technological change [5]. Regulatory compliance often requires adopting advanced, capital-intensive technologies, which may increase demand for skilled labor while reducing opportunities for less-skilled workers. This creates distributional impacts within the labor market: total employment may not fall substantially, but its composition can shift, with potential gains for high-skill workers and losses for low-skill employment.

Theoretical contributions also highlight the possibility of general equilibrium adjustments. Environmental regulations may reduce employment in directly regulated industries but stimulate job creation elsewhere, such as in the environmental goods and services sector (e.g., renewable energy, pollution control technologies). These offsetting dynamics suggest that the net employment effect depends on balancing job losses in traditional activities and gains in new or cleaner sectors. Taken together, these perspectives underscore that the employment effects of environmental regulation are theoretically ambiguous. They depend on the interaction of multiple forces—compliance costs, induced innovation, input substitution, and broader market dynamics. Several frameworks, including those of Morgenstern, Pizer, and Shih [30], have attempted to formalize these mechanisms by decomposing their effects into distinct channels. While this framework will be discussed in greater detail later, it is important to note that the existing theory clarifies that employment impacts cannot be signed a priori and must be established empirically.

3.2 Empirical evidence on employment effects of environmental policies

Empirical studies evaluating the labor market consequences of environmental regulation have expanded considerably over the past two decades. While early work often emphasized the risk of job losses in energy-intensive industries, subsequent research has shown that the impacts are more nuanced and generally smaller than initially feared. A brief synthesis of the studies covered in this literature review is described in Table 1.

In the U.S. context, Berman and Bui [7] examined oil refineries in Southern California, which are subject to some of the world's most stringent air quality standards. They found no evidence of significant employment declines—instead, firms adjusted by increasing capital intensity and improving productivity. Similarly, Greenstone [21] exploited variation from the Clean Air Act Amendments and identified modest reductions in industrial employment in nonattainment counties, although the effects were far less severe than commonly anticipated.

Table 1 Synthesis of some of the important empirical studies covered in the literature

References	Context	Methodology	Key findings
Popp et al. [34]	Pulp & paper (US)	Empirical (panel)	Policy drives adoption of cleaner technologies
Charles et al. [13]	US decarbonization	Simulation	Sector important for net-zero transition
Sajadi et al. [37]	Production processes	Simulation/AI	Efficiency gains via technological upgrades
Berman and Bui [7]	Air pollution regulation in the U.S. (South Coast Air Basin, Los Angeles)	Difference-in-differences using plant-level panel data	Finds little evidence that environmental regulation reduces employment; regulated plants did not experience significant job losses
Greenstone [21]	U.S. Clean Air Act (1970 & 1977 amendments) and manufacturing sector	Difference-in-differences exploiting non-attainment vs attainment counties	Environmental regulations reduced industrial activity, including employment and output in regulated areas
Marin and Vona [27]	French manufacturing sector; impact of energy price changes on firms	Panel data analysis with quasi-experimental variation in energy prices	Higher energy prices lead to a reallocation of labor toward more energy-efficient production, with limited negative effects on overall employment but evidence of structural adjustments
Cui et al. [19]	China's emission trading system (ETS)	Difference-in-differences using firm-level panel data	ETS lead to significant reductions in firm emissions, but showed negative impact on employment and capital input
Lu and Yang [26]	China's Environmental Protection Tax and firm-level outcomes	Triple difference estimator using firm-level panel data	Finds that environmental taxation leads to a reduction in employment, suggesting that stricter environmental regulation can have adverse labor market effects

European evidence reinforces this conclusion. Evaluations of the EU Emissions Trading System (EU ETS), the world's largest carbon market, suggest that it has limited employment effects despite compliance costs. Dechezleprêtre and Sato's [20] review concludes that the ETS reduced emissions while leaving employment largely unaffected. More granular analyses, such as Marin and Vona [27] for French manufacturing, highlight that regulation reshaped labor demand within firms: low-skill jobs declined slightly, while demand for higher-skill workers rose, consistent with the skill-biased technological change hypothesis. Emerging evidence from China echoes these findings. Studies of regional carbon trading pilots (e.g., [19, 26]) report negligible aggregate employment impacts, with modest shifts across sectors. These results suggest that while environmental regulations impose costs, firms often offset them through innovation, energy efficiency improvements, and organizational restructuring.

A growing body of literature has examined sustainability transitions and technological change in the pulp and paper industry. For instance, [34] analyzes the role of environmental policy and public pressure in driving the adoption of cleaner bleaching technologies. More recent studies highlight the sector's importance in achieving long-term decarbonization goals and improving production efficiency through technological innovation [13, 37]. In identifying energy-efficiency aspects, the obstacles to developing and following up key performance indicators in the sector constitute a major barrier to internal energy management [3]. While these studies focus primarily on environmental performance and technological advancement, relatively little attention has been paid to the labor-market implications of these regulatory and technological changes, particularly in developing economies. This paper addresses this gap by examining the employment effects of energy-efficiency regulation in the Indian pulp and paper sector.

The literature indicates that the employment impacts of environmental regulation are typically modest, heterogeneous, and mechanism-dependent. Effects are most potent in energy-intensive industries but are rarely economy-wide or catastrophic. This body of evidence underscores the importance of examining the specific channels—such as cost pressures, factor substitution, and demand shifts—through which environmental policies impact employment.

3.3 Evidence on the PAT scheme

The literature on PAT has primarily focused on its effectiveness in improving energy efficiency and reducing compliance costs, with relatively little attention paid to its labor market impacts. Macro shocks are more accurately estimated using methods such as the computable general equilibrium (CGE) model [29]. However, for assessing these kinds of micro shocks, most studies have employed the reduced-form differences-in-differences framework. Oak and Bansal [31] provide one of the first assessments, highlighting that PAT achieved significant energy savings in the fertilizer, pulp, and paper sectors. Through meticulous robustness tests, Chauhan and Thangavel [15] demonstrated a decrease in energy intensity in the iron and steel sector. Pal et al. [32] highlight the impact on energy intensity and firm value. After taking the sample pool of major sectors, the results indicated a non-significant reduction in energy intensity but a significant reduction in firm value. In the textile sector, Chauhan & Thangavel [16] measured a 3.9% decline in energy intensity due to the PAT scheme. This decrease, however, is found to be much more nuanced, at 13.1% in the pulp and paper sector, owing to investments in capital stock and improvements in labor utilization [14]. Besides energy consumption, Kumar and Agarwala [25] outline the characteristic features of the PAT scheme and renewable energy certificates, recommending coherence among various carbon trading mechanisms. Sahoo et al. [36] highlighted the need for more stringent energy-saving targets in the thermal power sector, citing unrealized potential. Furthermore, Bhandari and Shrimali [8] also highlight several inadequacies with the PAT scheme, including the lack of long-term investments and the absence of a PAT market.

However, the employment consequences of PAT remain largely unexplored. Most existing studies implicitly assume that efficiency improvements are cost-saving and therefore employment-neutral or positive. However, as theoretical and empirical evidence from other countries suggests, the labor market effects of environmental regulation are ambiguous and depend on various channels, including production costs, factor substitution, and demand dynamics. This gap is particularly notable in the pulp and paper sector, a highly energy-intensive industry crucial to India's PAT scheme and employing a large number of workers. By explicitly examining employment outcomes in this sector, the present study extends the literature on PAT. It contributes to the broader debate on whether energy efficiency regulations in developing economies are compatible with employment and industrial development objectives.

3.4 Mechanism framework

The net employment effect of environmental regulation is indeterminate because multiple adjustment channels operate simultaneously. A widely used approach to conceptualize these channels is provided by Morgenstern, Pizer, and Shih [30], who decompose the employment response into cost, factor-shift, and demand effects. Formally, firm-level employment L can be expressed in Eq. 1:

$$L = \frac{1}{P_L} \cdot \nu_L \cdot TC \tag{1}$$

where P_L is the wage rate, ν_L is labor's share in total cost, and TC denotes total costs of production (including regulatory expenditures). This identity highlights that employment is jointly determined by production costs, factor shares, and wages, which may be influenced by environmental policy. This expression highlights three distinct margins through which environmental regulation may affect employment.

The cost effect arises when regulation increases production costs TC by requiring firms to adopt new inputs, invest in monitoring systems, or incur compliance expenditures. Higher costs can reduce output and employment if firms are unable to pass them on to consumers fully. However, the adverse cost effect may be offset if regulation induces efficiency gains or innovation. This channel is empirically assessed by examining measures such as cost of goods sold (COGS) and research and development (R&D) expenditures. The description is given in Fig. 3.

The factor shift effect captures changes in the composition of inputs and outputs. Environmental compliance often requires upgrading capital equipment or reorganizing production processes, potentially substituting capital for labor. Conversely, labor demand may rise if compliance involves labor-intensive tasks such as monitoring, reporting, or maintenance. These dynamics can be proxied by the capital–labor ratio (K/L), which reflects changes in factor intensities.

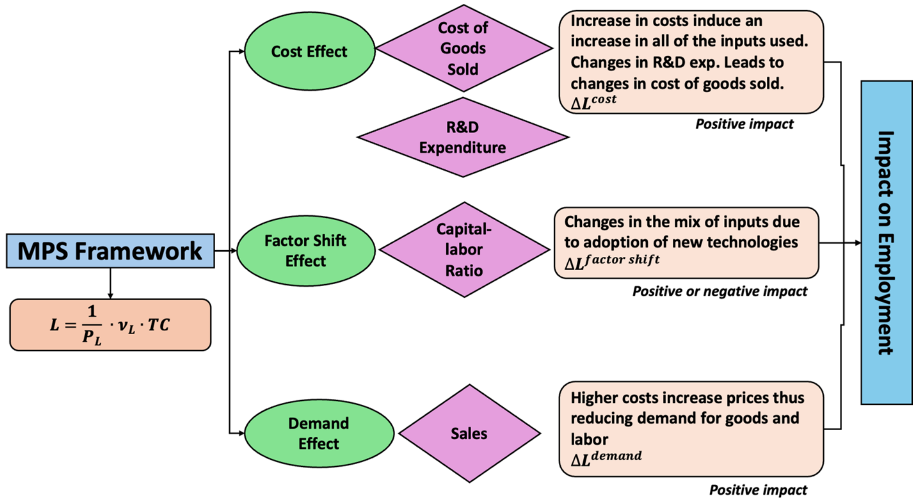

Fig. 3 Depiction of the mechanism framework of the study

Ultimately, the demand effect is realized through market adjustments. If regulatory costs increase output prices, demand for energy-intensive goods may decrease, leading to reduced employment. Alternatively, if regulation enhances competitiveness through innovation or product differentiation, demand and employment may increase. This effect is typically proxied by firm-level sales. Taken together, the MPS framework suggests that the total effect of regulation on employment is given in Eq. 2:

$$\Delta L = \Delta L^{cost} + \Delta L^{factorshift} + \Delta L^{demand} \tag{2}$$

where each component reflects one of the adjustment channels described above.

This study applies the framework to India's Perform, Achieve, and Trade (PAT) scheme in the pulp and paper sector. Specifically, we use firm-level data from the CMIE Prowess database to examine how the PAT scheme affected (i) production costs (via COGS and R&D expenditures), (ii) factor allocation (via capital–labor ratios and average wages), and (iii) product demand (via sales). This decomposition allows us to move beyond estimating the net employment effect and identify how energy efficiency regulation shapes firm-level labor demand in an emerging economy context.

4 Methodology

4.1 Methodology

This study employs a difference-in-differences (DID) framework to estimate the causal impact of India's Perform, Achieve and Trade (PAT) scheme on employment in the pulp and paper sector. The DID approach is well-suited for policy evaluation, as it compares changes in outcomes for treated firms (those covered by PAT) with changes for untreated firms (non-PAT firms), thereby controlling for time-invariant unobserved heterogeneity and standard macroeconomic shocks. This approach is well-suited for evaluating policy interventions in which treatment is assigned to a subset of firms and allows us to control for time-invariant firm characteristics and common macroeconomic shocks through firm- and year-fixed effects.

Formally, the estimating equation, as given in Eq. 3, is:

$$Lnemp_{it} = \alpha + \beta X_{it} + \gamma Treat_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{3}$$

where, $Lnemp_{it}$ is the natural log of the number of employees, $Treat_{it}$ is a treatment dummy equal to 1 if the firm i is covered under the PAT scheme in the year t and 0 otherwise, X_{it} is a vector of time-varying firm-level controls explained in Table, μ_i are firm fixed effects controlling for time-invariant characteristics such as location, management structure, or ownership, λ_t are year fixed effects capturing aggregate shocks such as changes in input prices or macroeconomic cycles, and ε_{it} is the idiosyncratic error term. The coefficient of interest, γ, captures the average treatment effect on the treated (ATT), i.e., the percentage change in employment associated with PAT participation, after controlling for firm and year effects. Since the dependent variable is in logs and the treatment is binary, γ the coefficient is interpreted as the semi-elasticity of employment with respect to the policy.

A key identifying assumption is the parallel trends assumption: in the absence of the PAT scheme, employment in treated and untreated firms would have followed similar trajectories. This assumption is tested using an event-study specification that includes leads and lags of the treatment indicator to examine pre-treatment dynamics. Given the possibility of serial correlation and cross-sectional dependence in firm-level panels, standard errors are clustered at the firm level, and robustness checks are conducted using Driscoll–Kraay corrections. Additional robustness is achieved through heterogeneity analysis (splitting firms by ownership, capital intensity, and export orientation) and mechanism analysis, where the DID is applied to cost, factor-shift, and demand-related variables, following the MPS [30] framework. The specification is given in Eq. 4:

$$\ln{(emp)}_{it} = \alpha + \sum_{k=-1} \delta_k D_{i,t-k} + \gamma X_{it} + \mu_i + \lambda_t + \epsilon_{it} \tag{4}$$

where:

- $D_{i,t-k}$ is a dummy variable that equals 1 if firm i is k years away from treatment in year t, and 0 otherwise.
- The reference year is $k = -1$ (one year before treatment), which is omitted to avoid perfect multicollinearity.
- δ_k captures the dynamic treatment effects relative to the base year.

The estimated coefficients δ_k for pre-treatment years (i.e., $k < 0$) are used to test for parallel trends. Statistically insignificant estimates in pre-treatment years suggest that there were no systematic differences in employment trends between treated and control firms prior to the implementation of the PAT scheme.

Graphical plots of these coefficients (with confidence intervals) provide a visual diagnostic of the trend structure and the dynamics of treatment effects over time. A significant divergence only after the treatment year strengthens the credibility of the causal interpretation of the DID estimates.

4.2 Data and variables

The empirical analysis is based on firm-level panel data from the Prowess database compiled by the Centre for Monitoring Indian Economy (CMIE). Prowess provides detailed financial statements, production accounts, and ownership information for Indian firms. This dataset extracts information on pulp and paper firms spanning the period 2002–2019, which covers two cycles of the Perform, Achieve and Trade (PAT) scheme. The

Table 2 Definition of variables of the study

Type	Variables	Symbol	Description
Dependent variable	Number of employees	*Lnemp*	The logarithm of number of employees
Independent variable	Policy	*Treat*	Interaction of group policy dummy and time policy dummy
Control variables	Average wage	*Wageperemp*	Ratio of total wages to number of employees
	Return on assets	*ROA*	Ratio of net profit to average total assets
	Profitability	*Profitability*	Ratio of net profit margin divided to total assets
	Cashflow	*Cashflow*	Ratio of net cash flow to total assets
	Age	*Lnage*	The Logarithm of firm's age plus one
	Size	*Size*	The Logarithm of total assets
	Capital Intensity	*Capint*	Ratio of net fixed assets to sales
Mechanism variables	Cost of goods sold	*LnCOGS*	The Logarithm of cost of goods sold including raw material, energy and labour
	R&D expenditure	*LnR&D*	The Logarithm of the research and development expenditure
	Capital-Labor ratio	*K/L*	Ratio of net fixed assets to number of employees
	Sales	*Lnsales*	The Logarithm of total sales

Table 3 Descriptive statistics of the main variables in the study

Variable	Obs	Mean	Std. Dev	Min	Max
Lnemp	281	6.152	1.398	1.099	8.764
Wageperemp	280	0.354	0.232	0.060	2.430
ROA	281	0.014	0.107	− 0.886	0.371
Profitability	257	− 1.505	16.911	− 198.573	0.198
Cashflow	251	0.499	3.400	− 11.728	42.970
Lnage	281	3.468	0.523	2.079	4.419
Size	278	7.528	1.395	3.033	10.338
Capint	278	0.719	1.092	0.105	11.543

sample is an unbalanced panel with missing observations in some years, but it includes both firms designated as PAT participants and comparable non-PAT firms. The variable descriptions are given in Table 2.

The outcome of interest is employment, measured as the number of employees reported by each firm. Following standard practice, employment is expressed in logarithmic form ($Lnemp_{it}$) to reduce skewness and allow for elasticity-based interpretation. The key explanatory variable is a dummy, $Treat_{it}$, which equals 1 if the firm i was covered under the PAT scheme in year t, and 0 otherwise. Information on PAT designation was obtained from the Bureau of Energy Efficiency (BEE) and matched with Prowess firm identifiers. This variable captures firms' exposure to binding energy-efficiency obligations under PAT.

Table 3 presents descriptive statistics for the main variables used in the analysis. The average firm employs approximately 470 workers, although there is substantial variation across firms, with employment ranging from very small to large-scale operations. Wage per employee also exhibits considerable dispersion, suggesting heterogeneity in skill composition and labor costs. Profitability indicators show significant variation across firms. While the average return on assets is relatively low, the wide range indicates that some firms experience substantial financial distress, whereas others remain highly profitable. Cash flow measures similarly display large dispersion, reflecting differences in financial conditions. Firms in the sample are generally mature, with an average age of over three decades, and vary considerably in size and capital intensity. The wide range in capital intensity suggests differences in production technologies and degrees of mechanization, which are particularly relevant for understanding the employment effects of energy efficiency regulations.

Two limitations should be noted. First, the analysis is restricted to PAT firms operating a single plant or having all of their plants covered under the PAT scheme. Due to data constraints, multi-plant firms with partial coverage could not be reliably assigned treatment status. While this reduces the breadth of the sample, it enhances the internal validity of the results by ensuring that the treatment definition is precise and not contaminated by partial exposure. This approach is consistent with best practices in program evaluation, which prioritize clarity of treatment assignment [4].

Second, data on employment in Prowess is limited, as disclosure of workforce numbers is not mandatory for Indian firms, and reporting practices vary across companies. This results in a relatively small number of firm-year observations compared to other financial variables. Nonetheless, employment is central to the policy question, and the available data, though limited, are sufficiently rich to permit firm- and time-fixed effects estimation, which helps to control for unobserved heterogeneity. Furthermore, robustness checks using alternative firm characteristics and mechanism analyses (e.g., costs, capital–labor ratios, sales) provide additional confidence that the results capture meaningful policy effects. These two limitations reduced the total number of firms to only 35, which encompassed the sample size of approximately 247.

While these constraints imply that the findings should be interpreted cautiously, they also underscore the study's originality. By leveraging the best available firm-level data, the paper contributes rare empirical evidence on the employment impacts of energy efficiency regulation in a developing country context. On this topic, systematic evidence remains scarce. To mitigate omitted variable bias, the regressions include a set of firm-level controls widely used in the literature on employment and environmental regulation, as described in the Table. The channels through which PAT may affect employment are constructed, aligning with the Morgenstern et al. [30] framework, and are presented as mechanism variables. All monetary variables are deflated to 2011–12 constant prices using sector-specific wholesale price indices (WPI) and consumer price indices (CPI), ensuring comparability across years. All other variables are in logged form except for ratios, which are used to measure them on the same scale and prevent outliers. If there were any outliers after scaling, they were winsorized accordingly.

5 Results and discussion

5.1 Baseline regression

Table 4 presents the baseline estimates of the impact of India's Perform, Achieve and Trade (PAT) scheme on firm-level employment. Across specifications, the treatment effect is negative and statistically significant, suggesting that compliance with the scheme was associated with reduced workforce levels among participating firms. In column (1), the estimated effect corresponds to an average decline of 12.8 percent in employment, while the more parsimonious specification in column (2) indicates a larger decline of nearly 50 percent. The robustness of the negative sign across specifications suggests that the policy generated labor-displacing pressures, though firm-level characteristics partly mediate the magnitude of this effect. It highlights that energy-efficiency

Table 4 Results of the baseline regression

Variables	**(1)**	**(2)**
	lnemp	***lnemp***
Wageperemp		−0.858***
		(0.252)
ROA		−0.117
		(0.239)
Profitability		0.0003
		(0.0003)
Cashflow		0.028***
		(0.005)
Lnage		0.677**
		(0.258)
Size		0.500***
		(0.091)
Capint		−0.080***
		(0.024)
Treat	−0.499***	−0.128*
	(0.105)	(0.067)
Constant	6.316***	0.590
	(0.058)	(1.130)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	281	247
R^2	0.20	0.61

Robust standard errors in parentheses

***$p<0.01$, **$p<0.05$, *$p<0.1$

regulation, while improving environmental performance, may impose short-run labor market adjustments on regulated firms. Empirical studies such as those of Lu and Yang [26], Cui et al. [19], and Greenstone [21] document the adverse labor-market effects of environmental regulation. However, the literature provides mixed evidence, as some studies find limited or no employment effects [7]. This finding is consistent with international evidence that environmental regulations impose modest but non-negligible labor market impacts, with the direction and magnitude shaped by firm-specific characteristics and adjustment capacity [1, 28].

This finding is broadly consistent with the factor-shift mechanism emphasized in the environmental regulation and employment literature. Policies such as PAT, which mandate energy savings in energy-intensive sectors, can raise production costs and encourage firms to substitute away from labor, mainly routine or low-skilled employment, toward energy-saving technologies or more efficient production processes [30, 38]. The adverse treatment effect aligns with international evidence suggesting that stringent environmental policies can reduce labor demand in affected sectors, at least in the short run, even as they may generate employment gains in clean energy or upstream industries [33].

Among controls, higher average wages are strongly associated with lower employment, reflecting a downward-sloping labor demand curve. Capital intensity similarly reduces labor demand, consistent with firms substituting capital for labor under tighter energy efficiency constraints [7]. By contrast, firm size, age, and cash flow positively relate to employment, indicating that larger, older, and financially healthier firms are better positioned to sustain their workforce despite compliance costs. Short-term profitability measures, such as ROA and profit margins, are not statistically significant, echoing evidence that employment adjustments are more sensitive to structural and financial variables than to transitory profitability shocks [30, 38].

Overall, these results provide evidence that the PAT scheme had a measurable dampening effect on employment in regulated firms, underscoring the potential trade-offs between energy-efficiency improvements and labor demand. At the same time, they emphasize the importance of examining adjustment channels—such as changes in capital intensity, R&D investment, or wage structures—and heterogeneity across firm types, to better understand whether such regulations generate longer-term productivity gains or induce structural shifts in the labor market. The PAT scheme contributed to capital-deepening and cost-adjustment responses that reduced labor demand.

5.2 Robustness tests

5.2.1 Parallel trends test

Figure 4 plots the dynamic treatment effects relative to the treatment year, along with 95 percent confidence intervals. The estimates suggest some fluctuation in employment levels over time: employment initially increases, then declines, becoming sharper after the scheme's implementation. Following treatment, employment continues to fall through post2 before reducing the decline rate.

Importantly, all of these pre-treatment coefficients are statistically different from zero, supporting the validity of the parallel trends assumption that underpins the DID framework. This suggests that, prior to the implementation of PAT, treated and control firms followed broadly similar employment trajectories. While the post-treatment coefficients remain statistically significant, their oscillating pattern suggests that employment effects of PAT may not be immediate or monotonic, but instead reflect gradual adjustment processes. This is consistent with evidence from the environmental regulation literature, which finds that firms often experience transitional disruptions followed by partial recovery as they adapt to new requirements [7, 38] . The event-study results lend credibility to the DID identification strategy while highlighting the possibility of

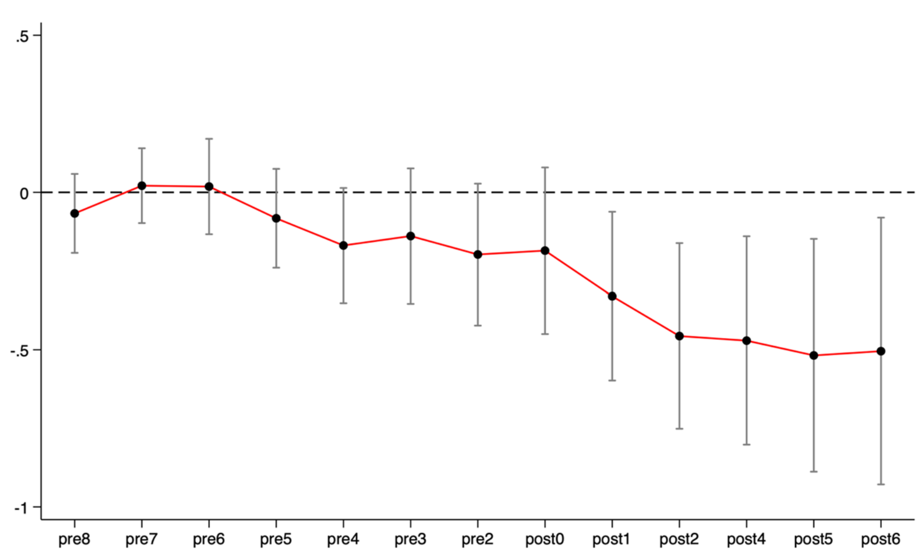

Fig. 4 The depiction of the parallel trends assumption

nuanced adjustment dynamics around policy implementation, even if the average effects are harmful, as shown in the baseline regressions.

5.2.2 Placebo tests

To rule out the possibility that the baseline regression outcome results from chance, placebo tests are conducted to ensure its validity. Figure 5 shows the permutation distribution of the treatment effect based on 5000 random reassignments of the treatment variable. The kernel density of the placebo estimates is centered at zero, confirming that the expected effect vanishes under random assignment. The dashed vertical line indicates the null value of zero, while the dashed horizontal line marks the baseline regression *p*-value of 0.065. The observed estimate lies in the lower tail of the distribution, with most placebo estimates generating higher *p*-values. This suggests that the baseline effect is unlikely to be due to chance.

5.2.3 Alternative dependent variable

In this sub-section, a robustness test is conducted by replacing the dependent variable with the log of total wages (*Lnwages*). In the literature, wages are often used in conjunction with employment as an additional measure of labor outcomes affected by environmental policies, as seen in a study by Cong et al. [18]. The result of the regression is presented in Table 3. The variable *Treat* remains significant, although its magnitude is larger than in the baseline regression. So, the PAT scheme reduced the number of employees and the total wage bill in the pulp and paper sector, suggesting that the choice of labor outcome measure does not drive the results.

5.2.4 Alternative control variables

In this additional robustness test, alternative control variables are used in place of the existing ones. In Table 5, column 2, asset-related variables, i.e., ROA, profitability, cashflow, and capital intensity are replaced with other variables. The debt-to-asset ratio (*DA*), a measure of leverage, the fixed assets ratio (*FAR*), and export intensity (*Expint)* are introduced. Other firm characteristics remain in the baseline regression. The PAT

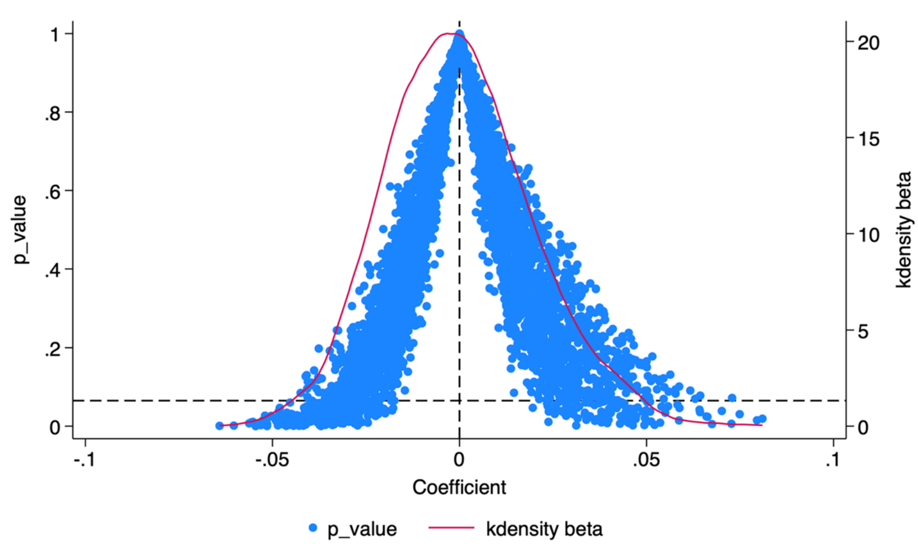

Fig. 5 Placebo tests of the baseline regression result

Table 5 Robustness tests of the study

Variables	(1)	(2)
	Lnwages	***Lnemp***
Wageperemp		− 0.882*
		(0.503)
ROA	− 0.0499	
	(0.344)	
Profitability	0.001	
	(0.001)	
Cashflow	0.010	
	(0.011)	
Lnage	0.845**	0.661
	(0.396)	(0.576)
Size	0.491***	0.425***
	(0.101)	(0.149)
Capint	− 0.001***	
	(0.000)	
DA		0.031
		(0.175)
FAR		-0.465
		(0.280)
Expint		0.316
		(0.959)
Treat	− 0.339***	− 0.174**
	(0.097)	(0.078)
Constant	− 1.654	1.615
	(1.193)	(2.805)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	462	131
R^2	0.513	0.517

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

scheme's impact on employment is negative and is significantly similar to the baseline regression result. Thus, the baseline result remains consistent even after controlling for various covariates.

5.2.5 Trimming observations by size

As a robustness test, the sample size has been reduced by trimming the observations falling in the bottom 1 and top 99 percentiles. By capping observations, any outlier effect on the regression results would thus be eliminated. The regression results after trimming observations are reported in Table 6. As shown in column 2, the policy variable *'Treat' remains* negative and significant, with a baseline magnitude of 0.129. Even after excluding the control variables, the result of column 1 matches the baseline result of 0.499 in Table 2. So, the baseline result is robust to extreme observations.

5.3 Mechanism analysis

To better understand the pathways through which the PAT scheme influences firm-level employment, we build on the framework of Morgenstern, Pizer, and Shih [30], which decomposes the employment effects of environmental regulation into three distinct channels: the cost effect, the factor-shift effect, and the demand effect. This approach

Table 6 Regression results after trimming observations by size

Variables	(1)	(2)
	Lnemp	***Lnemp***
Wageperemp		−0.862***
		(0.252)
ROA		−0.129
		(0.238)
Profitability		0.0003
		(0.0003)
Cashflow		0.028***
		(0.005)
Lnage		0.672**
		(0.258)
Size		0.499***
		(0.091)
Capint		−0.080***
		(0.025)
Treat	−0.532***	−0.129*
	(0.099)	(0.068)
Constant	6.392***	0.623
	(0.056)	(1.141)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	275	244
R^2	0.246	0.612

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

allows us to move beyond estimating the average treatment effect and examine the mechanisms underlying employment adjustments. Specifically, we test whether higher compliance costs, shifts in the input mix between labor and capital, or changes in product demand drive the observed employment effects of PAT. The following subsections present evidence on each of these channels.

5.3.1 Cost effect

The estimates reported in Table 7 provide evidence on the cost-effectiveness of the PAT scheme, following the MPS framework [30]. Column (1) shows that COGS is strongly and positively associated with employment, indicating that firms with higher production costs tend to maintain larger workforces. This aligns with the intuition that COGS partly reflects labor-related expenditures, and higher production activity levels require more employees.

Regarding the policy effect, column (2) demonstrates that PAT participation is associated with a significant reduction in COGS, with an estimated decline of over 28 percent. At first glance, this result appears counterintuitive, as compliance with energy-efficiency regulation is often expected to raise costs by necessitating new investments or operational changes [30]. However, this decline is consistent with studies showing that energy-efficiency mandates can generate process improvements that reduce input use and rationalize expenditures, particularly in energy-intensive industries [35]. In other words, PAT may have induced firms to reorganize production and adopt efficiency-enhancing measures that lowered reported costs, even as they reduced employment.

Table 7 Results of the cost effect

Variables	(1)	(2)	(3)	(4)
	Lnemp	***LnCOGS***	***Lnemp***	***LnR&D***
LnCOGS	0.573***			
	(0.110)			
Treat	−0.058	−0.273***	−0.139	0.312*
	(0.086)	(0.064)	(0.087)	(0.152)
LnR&D			−0.023	
			(0.028)	
Constant	0.979	1.220	−4.144	−26.430***
	(1.714)	(0.836)	(3.251)	(5.166)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	248	248	97	127
R^2	0.65	0.71	0.84	0.63

Robust standard errors in parentheses

***$p<0.01$, **$p<0.05$, *$p<0.1$

Table 8 Results of the factor shift effect

	(1)	(2)
	Lnemp	***K/L***
Treat	−0.159***	−0.003
	(0.053)	(0.004)
K/L	−11.300***	
	(2.320)	
Constant	6.824***	0.013
	(0.245)	(0.011)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	248	248
R^2	0.586	0.126

Robust standard errors in parentheses

***$p<0.01$, **$p<0.05$, *$p<0.1$

To probe this further, columns (3) and (4) explore the role of R&D investment as a potential driver of cost reductions. The estimates suggest that PAT firms increased R&D expenditure significantly following regulation, while the relationship between R&D and employment is negative, though not statistically significant. This pattern is consistent with the induced innovation hypothesis [33], which posits that environmental regulation stimulates technology-enhancing investment, thereby increasing efficiency but potentially reducing labor demand in the short term, particularly for lower-skilled tasks. These results suggest that the decline in COGS among treated firms is not merely an accounting artifact but reflects genuine efficiency gains, facilitated in part by higher R&D spending, with implications for employment adjustments.

5.3.2 Factor shift effect

Table 8 examines the factor-shift channel, which describes how environmental regulation affects the input mix between labor, capital, and skills. Column (1) shows that the capital–labor ratio (K/L) is strongly and negatively associated with employment, implying that greater capital intensity substitutes for labor. This is consistent with classic

Table 9 Results of the demand effect

Variables	(1)	(2)
	lnemp	***lnsales***
treat	−0.051	−0.511***
	(0.094)	(0.091)
lnsales	0.541***	
	(0.116)	
Constant	1.126	3.654**
	(1.783)	(1.422)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	247	247
R^2	0.628	0.651

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

theories of factor substitution in response to regulatory costs [7], in which firms reduce their reliance on labor as capital- or energy-saving technologies become more attractive.

Column (2) shows that the treatment effect on K/L is negative but statistically insignificant. This suggests that while employment outcomes are sensitive to firms' capital intensity, PAT did not significantly alter the relative use of capital to labor at the firm level. Instead, the evidence points to broader labor-saving responses, possibly through efficiency improvements or organizational restructuring, rather than a mechanical shift in capital–labor proportions.

These results align with the MPS framework, which predicts that environmental regulation can influence employment through factor reallocation [30]. Similar findings are reported in U.S. and European manufacturing studies, where energy or pollution abatement policies induced labor-saving technological change without systematically increasing capital intensity [7, 28]. Thus, the evidence indicates that the PAT scheme's employment effects are better understood as labor-demand reductions driven by efficiency pressures rather than as outright capital deepening.

5.3.3 Demand effect

Table 9 assesses the demand channel, which considers whether environmental regulation affects employment through its impact on output demand and sales. Column (1) confirms that sales are strongly and positively correlated with employment: a 1 percent increase in firm sales is associated with a 0.54 percent increase in employment. This elasticity highlights the significance of market demand in sustaining labor demand, aligning with the literature on output–employment linkages in energy-intensive industries [7] (Greenstone et al. 2012).

Turning to the impact of the PAT scheme, column (2) shows that treated firms experienced a significant decline in sales, with an estimated reduction of approximately 51 percent. This finding suggests PAT participation may have constrained output demand by increasing compliance costs passed on to customers, causing production disruptions during technology upgrades, or prompting competitive shifts vis-à-vis untreated firms. Such effects are consistent with concerns raised in the environmental economics literature that regulation can depress demand in regulated sectors, even as it improves energy efficiency [20].

The results indicate a demand-side mechanism in which PAT reduced firm-level sales, thereby contributing to lower employment. Unlike the cost or factor-shift effects, which reflect adjustments within production, the demand channel highlights the role of market dynamics in transmitting the effects of regulation to the labor market.

6 Conclusion and policy recommendations

This paper examines the labor-market effects of India's Perform, Achieve, and Trade (PAT) scheme in the pulp and paper sector, using firm-level data from 2002 to 2019 across two cycles. Employing a difference-in-differences framework with firm- and year-fixed effects, we find that PAT adoption is associated with a statistically significant decline in employment, with average estimates ranging from 10 to 13%. Although modest in absolute terms, this contraction highlights the labor-market implications of energy-efficiency regulation in an industry where employment generation remains a key policy concern.

Our mechanism analysis, guided by the Morgenstern et al. [30] framework, suggests that three channels jointly drive the employment response. First, cost effects are evident: firms reduced the cost of goods sold, partly through efficiency gains and substitution away from labor inputs. Second, factor-shift effects emerge through higher capital–labor ratios and rising average wages, consistent with increased reliance on more skilled labor and capital-intensive production technologies. Finally, demand-side effects, reflected in lower sales growth for PAT firms, contributed to employment contraction by dampening output expansion. Taken together, these results indicate that compliance with the PAT scheme prompted firms to restructure production in ways that were not employment-neutral.

From a policy perspective, the findings underscore the need to balance climate and employment objectives in energy-intensive industries. Energy conservation is crucial not only for resource savings but also for addressing broader climate concerns. However, as the most populous country, India must also closely monitor the risks of employment loss while actively fostering new employment opportunities. While the PAT scheme has successfully incentivized efficiency improvements, its employment consequences underscore the importance of complementary labor market policies.

The findings of this study have important policy implications. First, skill development and retraining programs should be integrated into industrial energy efficiency policies to ensure that workers displaced by capital-deepening transitions are absorbed into upgraded roles. Second, targeted fiscal incentives, such as wage subsidies for green jobs or concessional credit for labor-intensive energy-efficient technologies, could help offset potential employment losses. Third, the subsequent phases of PAT and similar schemes in other sectors should explicitly incorporate employment metrics into monitoring and evaluation frameworks, ensuring that regulatory stringency does not disproportionately harm job creation in labor-abundant contexts. While environmental regulation can deliver energy efficiency and climate benefits, its labor market implications warrant equal policy attention. By demonstrating both the magnitude and mechanisms of employment effects in India's pulp and paper sector, this paper contributes to a more nuanced understanding of "just transitions" in emerging economies.

This study is subject to certain limitations. In particular, the analysis is constrained by the availability of firm-level employment data, which limits the sample size. Additionally, the absence of detailed information on workforce composition prevents a more disaggregated analysis of skill-specific employment effects. Future research could extend this analysis by examining the differential impact of environmental regulation across skill categories and exploring longer-term employment dynamics. Further work could also investigate spillover effects across related industries and the role of complementary policies in mitigating potential trade-offs between environmental and employment objectives.

Author contributions
Anushka Chauhan: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing—original draft, Visualization. Dr. T. Mohanasundari: Validation, Resources, Supervision, Writing—review & editing.

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Data availability
The data that support the findings of this study are available from the Centre for Monitoring Indian Economy (CMIE). Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the authors upon reasonable request with the permission of the CMIE.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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