

Article

Task Embedding Under Carbon Pricing: How China's National Carbon Emissions Trading System Reshapes Green Jobs Within Firms

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Abstract

As a key market-based instrument for low-carbon transition, China's national carbon emission trading market facilitates emission abatement and reshapes labor allocation in regulated firms. Based on the task-based framework, a task embedding hypothesis is proposed. Restricted by organizational adjustment costs, firms tend to integrate green compliance tasks into existing roles instead of massively establishing specialized green positions. Using 13 million job postings and matched financial data of Chinese A-share listed firms from 2016 to 2024, this study regards the launch of the national carbon market as a quasi-natural experiment and adopts a difference-in-differences (DID) approach. The results indicate that the carbon market raises the green job share of regulated enterprises by 4.7 percentage points. Such growth is not driven by newly built environmental departments. Management compliance posts decrease markedly, technical posts remain stable, while task-embedding positions combining traditional and green tasks dominate the growth effect. Heterogeneously, private enterprises and eastern China dominate the transformation, while state-owned enterprises lag behind and central and western regions witness a green job share decline. This study enriches task-based theory application in environmental regulation and provides empirical implications for sustainable green talent development and just transition policy design.

Keywords: carbon emissions trading system; green jobs; task embedding; difference-in-differences; sustainable employment transition; China



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1. Introduction

The employment implications of carbon trading have been one of the most widely debated issues in environmental economics in recent years. The existing literature has extensively examined the effects of carbon trading, or environmental regulation more broadly, on key variables such as corporate investment, technological innovation, and output. The studies that do address labor have focused mainly on aggregate or distributional outcomes captured by stock indicators. For instance, Luo et al. find that China's carbon trading pilots lowered firms' labor income share [1], while Ma et al. show that the scheme raised corporate labor costs by upgrading the human capital structure [2]. Valuable as they are, these studies infer labor effects from firm-level stock measures and leave the internal job structure unexamined. As a result, the impact of carbon trading on intra-firm labor reallocation—how regulated firms reshape the composition of jobs and the task content of existing roles—has

yet to receive adequate attention. Against the backdrop of an increasingly challenging labor market, the employment implications of carbon market operations have emerged as a pressing concern. Key questions include whether the expansion of carbon markets exerts a crowding-out effect on employment, how firms reallocate human resources in response to rising carbon compliance costs, and whether an irreconcilable tension exists between the green transition and employment stability. These questions are not only of significant academic interest but also bear directly on the sustainable advancement of carbon market policies and the realization of the “just transition” goal [3].

To achieve the carbon peak and carbon neutrality targets, China officially launched its national carbon emissions trading market (ETS) in July 2021, initially covering 2162 emission-regulated enterprises in the power sector and approximately 4.5 billion tons of carbon dioxide emissions, making it the world’s largest carbon market in terms of covered emissions volume. As a market-based environmental regulation policy instrument, the carbon market internalizes emission costs into firms’ production and operational decisions, theoretically achieving emission reduction targets at the lowest social cost [4,5]. However, while driving emission reductions, the carbon market inevitably triggers adaptive responses from firms at the micro level, thereby inducing broader resource reallocation, particularly the reallocation of labor resources.

Research on the relationship between environmental regulation and the labor market has generated a substantial body of empirical evidence and theoretical insights. However, a consensus has yet to be reached, and these studies have not penetrated to the core of the specific domain of carbon trading. For example, some studies find that environmental regulation increases firms’ compliance costs, resulting in a contraction in labor demand in regulated industries [6,7]. In contrast, the Porter hypothesis and its extensions argue that well-designed environmental regulation can stimulate innovation, enhance productivity, and ultimately generate new employment opportunities [8,9]. This divergence largely stems from researchers’ use of different regulation indicators, employment measures, and identification strategies. A more fundamental issue is that this body of literature has focused primarily on the quantitative dimension of employment—that is, whether the carbon market leads firms to hire more or fewer workers—while neglecting changes in the quality and structure of employment.

In fact, when firms face carbon market shocks, deeper adjustments often occur within the job structure: some positions expand while others contract, and the task composition within jobs shifts as well. These shifts in the quality and structure of employment reveal the true policy impact far more clearly than changes in aggregate employment. In recent years, the task-based framework proposed by Acemoglu and Autor offers a useful theoretical lens for analyzing such structural shifts [10]. Drawing on Dutch employer–employee matched data, Elliott et al. show that eco-product innovation increased green jobs by approximately 19.7% while total employment remained unchanged, demonstrating that structural changes lie beneath stable aggregate employment [11].

These studies, however, focus on European and North American labor markets, and we know relatively little about how the rollout of China’s carbon market is reshaping firms’ green job structures. China’s carbon market carries several distinctive institutional features. State-owned enterprises occupy a dominant position in high-emission industries; the stringency of environmental enforcement varies sharply across regions; and the flexibility and mobility of the labor market differ markedly from those of developed economies. In recent years, although some scholars have begun to examine the impact of carbon trading policies on total employment, labor income shares, and labor investment efficiency, the existing literature shares a common limitation: by relying on stock measures such as “total number of employees”, it treats the firm as a black box, thereby overlooking the dynamic

reorganization of jobs taking place within it. Moreover, most existing studies center on the regional carbon trading pilots launched after 2013 rather than the national carbon market introduced in 2021, and these two differ significantly in coverage, the mechanisms of allowance allocation, and market liquidity. We focus on China for three reasons that make it an especially informative setting rather than an arbitrary one. First, China operates the world's largest carbon market by covered emissions, so its consequences for the labor market are of major policy importance. Second, the coexistence of dominant state ownership in sectors with high emissions, sharp regional variation in enforcement, and a labor market whose flexibility differs markedly from developed economies generates institutional variation that is difficult to observe elsewhere and that is central to our mechanism. Third, the availability of large volumes of online recruitment data for Chinese listed firms makes it feasible to observe the reorganization of tasks within firms directly, which is precisely the dimension that previous work based on data from multiple countries could not capture. Therefore, this paper focuses on a core question that has yet to be adequately answered: how has the national carbon emissions trading market actually reshaped firms' green job structures? Specifically, we pursue this question along three dimensions. First, whether the carbon market has significantly increased the share of green jobs in firms is identified. Second, the underlying transmission mechanism is clarified, specifically whether this increase is achieved through the creation of dedicated environmental departments or through embedding green tasks into traditional positions. Third, the heterogeneity in job structure adjustments across firms with different ownership types and geographic locations is examined.

This paper makes three contributions. First, on the data front, the limitations of traditional stock data from annual financial reports are overcome by using large-scale recruitment data covering approximately 13 million job-level postings, accurately capturing firms' proactive demand signals for green talent. Compared with stock indicators such as total number of employees, the job posting data used in this paper respond more sensitively to firms' immediate organizational adjustments under carbon market shocks, and in particular, make it possible to distinguish changes in demand across different types of positions. Second, on the theoretical front, the task embedding hypothesis is introduced and systematically validated. Contrary to the prevailing arguments in the literature that environmental regulation either directly generates a wave of dedicated green jobs or drives a transition from brown jobs to green jobs, we find that Chinese firms follow a distinct response path when facing carbon market pressures: they embed green compliance tasks into the responsibilities of existing positions, adapting at minimal organizational change cost. This finding broadens the application of task-based theory within environmental regulation research. Third, on the policy front, we document pronounced heterogeneity in the labor effects of the carbon market across ownership types and regions. Non-state-owned enterprises and firms located in the eastern region, where environmental enforcement is stricter, emerge as the principal drivers of green job transformation, whereas state-owned enterprises and firms in the central and western regions show notably weaker responses. These findings offer concrete empirical grounding for designing complementary policies as the carbon market continues to expand.

The remainder of the paper proceeds as follows. Section 2 reviews the relevant literature and develops the theoretical mechanism and hypotheses. Section 3 describes the data and variables and sets out the empirical strategy. Section 4 presents the baseline regression and robustness checks. Section 5 reports the mechanism tests and heterogeneity analysis. Section 6 concludes and discusses policy implications.

2. Literature Review and Theoretical Analysis

2.1. *The Impact of Environmental Regulation on the Labor Market: From the “Quantity” Debate to “Structural” Analysis*

The literature in this area resides at the intersection of environmental economics and labor economics. Early studies predominantly focused on the aggregate employment effects of environmental regulation. Gray and Shadbegian systematically review the theoretical frameworks and empirical progress in this field and note that most studies converge on two questions: whether environmental regulation reduces labor demand at regulated firms, and how such effects are distributed across different worker groups [12]. Empirical findings, however, remain mixed. Yamazaki finds that the carbon tax policy in British Columbia, Canada, had a modest positive impact on aggregate employment [13]. However, by examining the U.S. Nitrogen Oxides Budget Trading Program (NBP), Curtis reports a roughly 1.3% employment decline in regulated areas, with employment losses disproportionately concentrated among low-skilled workers [14]. From a factor substitution perspective, Hille and Möbius show that rising energy prices induced firms to substitute labor for energy, increasing labor demand in some sectors [15]. Taken together, these studies, based on data from different countries or regions, have yet to yield a consensus.

More recently, researchers have moved beyond the quantity dimension to examine how environmental regulation reshapes the structure and quality of employment. For example, drawing on data from EU countries, Marin and Vona find that climate policy is distinctly skill-biased: rising energy prices significantly boost the demand for high-skilled technicians and professionals while reducing the demand for low-skilled manual workers [16]. Curtis et al. trace the transition from brown jobs to green jobs in the United States and find that although the rate of brown-to-green occupational transition rose tenfold over more than a decade, the overall successful transition rate remained extremely low, at less than 1% [17]. Popp et al. further find that the development of clean energy technologies generates particularly pronounced demand for engineering and scientific skills [18]. These findings indicate that focusing solely on aggregate employment risks overlooking the deep structural adjustments within the labor market triggered by environmental regulation, and that the reconfiguration of skill demand and the transformation of job attributes embedded in those adjustments may be the principal channel through which policy effects operate.

2.2. *The Employment Effects of Carbon Emissions Trading Systems*

Since 2011, China has gradually rolled out regional carbon emissions trading pilots, eventually establishing local carbon trading markets in eight provincial-level regions. Building on the experience accumulated through these regional pilots, the unified national carbon emissions trading market was officially launched in 2021. What, then, are the economic and especially employment consequences of these regional pilots and the national market? Using the implementation of China’s revised Environmental Protection Law as a quasi-natural experiment, Liao et al. find that the impact of environmental regulation on firm-level employment exhibits nonlinear characteristics, with more pronounced effects in pollution-intensive firms [19]. Additionally, Wang et al. investigate the impact of carbon emissions trading policy on firms’ labor demand and find that the policy raises firms’ demand for high-skilled labor [20].

However, the above literature faces two common limitations. First, the employment measures it relies on are aggregate stock indicators which are principally “total number of employees” drawn from the CSMAR database, which cannot detect structural shifts within job compositions. Firms can significantly restructure their job configuration while maintaining stable aggregate employment, dismissing dedicated environmental specialists and adding hybrid roles that integrate production and environmental responsibilities. Yet

none of this reshaping shows up in stock-level data. Second, this work centers on regional carbon trading pilots launched from 2013 onward rather than the national carbon market launched in 2021, even though the two systems differ substantially in terms of coverage, allowance allocation, and market liquidity. These two limitations—employment measures confined to aggregate stock levels and a policy focus restricted to regional pilots—open a clear research space for using job-posting data to study the employment structure effects of the national carbon market.

2.3. Definition, Measurement, and Task-Based Analysis of Green Jobs

How to define and measure “green jobs” remains a fundamental methodological issue in this field. Approaches have evolved sequentially, from occupational classification, to task analysis, and finally to text mining of job posting.

Early studies largely defined green employment based on occupational classification systems. Consoli et al. were the first to systematically compare the skills and human capital differences between green and non-green jobs, finding that green jobs require substantially higher levels of engineering and technical skills, thus establishing the stylized fact that “green jobs are skill-biased” for subsequent studies [21]. Building on this, Vona et al. develop a measurement method for measuring green skills and green tasks based on the O*NET database [22]. This method no longer simply labels certain occupations as “green” in their entirety but instead delves into the level of specific tasks within occupations, identifying which work tasks possess environmental attributes. This framework subsequently became a standard tool in the field, adopted and extended by numerous later studies. Their analysis shows that more green-intensive occupations rely heavily on technical and engineering skills to address and implement specific environmental solutions. Vona et al. extend this method to U.S. local labor markets, estimating that green jobs account for approximately 2–3% of the U.S. labor market and that green jobs command an average wage premium of about 4% [23].

The recent proliferation of online job-posting data has enabled researchers to extract information on green skills and jobs directly from recruitment text. Saussay et al. use U.S. online job posting data to construct the skill profile of low-carbon jobs, finding that low-carbon jobs require not only more technical skills but also higher cognitive abilities and IT skills [24]. Using cross-country microdata from the IMF, Bluedorn et al. systematically classify green and brown jobs along the task dimension and found that workers with green skills display greater employment resilience during periods of economic uncertainty [25].

In the Chinese context, however, the identification of green jobs presents unique challenges. China has no standardized task classification database analogous to O*NET. The alternative strategy employed in this study is to identify green jobs using keywords drawn from job titles and job categories within recruitment postings, such as environmental protection, energy conservation, emission reduction, carbon management, etc. The procedure is operationally transparent and replicable, but it has a clear limitation: it can miss task-embedding positions whose titles do not explicitly signal green content even though their actual responsibilities already include green tasks. For example, a position titled “production supervisor” that has been assigned carbon emissions monitoring responsibilities will not be flagged as green through keyword matching. However, this omission does not introduce systematic bias into our difference-in-differences estimates. The difference-in-differences estimator remains unbiased as long as this omission does not differ systematically between the treatment and control groups, that is, as long as the carbon market shock does not raise the omission probability in the treatment group relative to the control group. Indeed, if such omission is present, the green-job effect estimated in

this paper represents a lower bound on the true policy effect and the actual impact of the carbon market on firms' green job configuration is likely larger than what we report.

To ensure transparency and replicability, we describe the classification procedure in detail. The procedure has two steps: identifying green jobs, and assigning green jobs to position types.

In the first step, for each job posting we scan two text fields, the job title and the job description. A posting is classified as a green job if either field contains any keyword from our green keyword dictionary. The dictionary covers four groups of terms: (i) general low-carbon terms, including green, low-carbon, environmental protection, energy conservation, emission reduction, carbon peaking, and carbon neutrality; (ii) carbon management and market terms, including carbon emissions, carbon assets, carbon trading, carbon allowances, carbon accounting, carbon verification, carbon footprint, ESG, green electricity, and green certificates; (iii) pollution control and environmental engineering terms, including environmental engineering, wastewater treatment, desulfurization, denitrification, dust removal, waste gas, and solid waste; and (iv) new energy and energy efficiency terms, including new energy, environmental equipment, energy efficiency, integrated energy, and life-cycle assessment. The firm-level green job share is the number of green job postings divided by the firm's total job postings in a given year.

In the second step, we assign green jobs to three position types according to the nature of the task and where the green signal appears in the posting. The three types are defined independently of one another using keywords and the location of the green signal; they are therefore neither mutually exclusive nor collectively exhaustive, and the corresponding regression coefficients should be read as three independent mechanism tests rather than as an additive decomposition of total green jobs. (a) Compliance-management positions are those whose title or description contains compliance and carbon-management terms, such as carbon accounting, carbon verification, carbon assets, carbon trading, information disclosure, ESG, compliance, auditing, and environmental management. These correspond to the "internal specialization" strategy on its managerial side. (b) Technical positions are those whose title or description contains technical and engineering terms, such as research and development, engineer, process, low-carbon technology, emission reduction, environmental equipment, new energy, energy conservation, and retrofitting. These correspond to the technical side of internal specialization. (c) Hybrid task-embedding positions are those whose title is a conventional, non-green job (containing no green keyword), but whose description contains green keywords. This last category is the direct operationalization of task embedding: it captures conventional positions, such as production supervisors, procurement managers, or administrative staff, into which green compliance tasks have been incorporated, rather than newly created dedicated green positions.

The key distinction is that compliance-management and technical positions are defined by the professional nature of the task, whereas hybrid positions are defined by the location of the green signal, namely a conventional job title combined with green content in the job description. The classification relies entirely on observable recruitment text and a fixed keyword dictionary; given the same data and dictionary, the procedure is fully replicable and does not depend on the researcher's discretion.

2.4. Theoretical Mechanism: The Task Assignment Model and the "Task Embedding" Hypothesis

The theoretical foundation of this study is the task-based framework of Acemoglu and Autor, which reconceptualizes production as the execution of a continuum of discrete tasks rather than the deployment of an undifferentiated stock of labor. In this framework, a job is a bundle of tasks, and the assignment of tasks to jobs is not fixed. Firms can reassign tasks across jobs, redraw the boundaries of existing roles, and change the skill content

required of a position without necessarily changing the number of workers they employ. An exogenous shock that changes the set of tasks a firm must perform, such as a new regulatory requirement, therefore works through the way tasks are allocated to jobs and reshapes the composition and skill requirements of jobs even when aggregate employment remains unchanged. This framework provides the micro-foundation for the green-task measurement tradition reviewed in Section 2.3. In task-based terms, the “greening” of work documented by that literature amounts to the introduction of green tasks into a firm’s existing set of tasks. Such green tasks may be concentrated in dedicated positions, or they may instead be distributed across conventional roles. The task-based framework makes this second case visible: green tasks may be embedded into traditional jobs rather than confined to dedicated positions. We develop this possibility into a testable hypothesis below. This task-based perspective is what allows us to ask not whether the carbon market changes how many workers firms hires, but how it changes the tasks those workers are asked to perform.

We draw on the task-based framework to unpack the micro-level transmission mechanism of the national carbon market shock. In this framework, a firm’s production activities consist of a series of heterogeneous tasks allocated to workers of varying skill levels. The introduction of the national carbon market fundamentally alters the task space facing regulated firms. Beyond traditional production and operational tasks, these firms are now legally required to perform a series of new green compliance tasks, including accounting for and reporting carbon emissions data, trading and management of emission allowances, implementing energy-saving and emission-reducing technological retrofits, and disclosing ESG information in line with regulatory requirements. These new tasks require corresponding human resources to carry them out and in doing so trigger a need to reorganize the firm’s job structure. New tasks created by low-carbon technologies are typically ill-defined and difficult to standardize, and depend on tacit knowledge for incremental improvement and execution. Firms therefore cannot dispatch them through simple rules or standard operating procedures alone but must instead rely on human resources equipped with relevant knowledge.

Confronted with a surge in green tasks, rational firms under organizational constraints typically face a trade-off among three organizational response strategies, and this trade-off constitutes the core theoretical hypothesis of this paper. The first strategy is internal specialization, under which firms establish dedicated environmental management departments and hire specialized environmental staff extensively to absorb the full set of green tasks. However, such specialized staff do not directly generate revenue, and the search and matching costs are steep. Under the financial pressure imposed by carbon prices, firms who wish to avoid prohibitive fixed labor costs will not only refrain from creating such positions on a large scale but may even, driven by cost-control imperatives, lay off existing redundant compliance staff. The second strategy is environmental service outsourcing. For new tasks with extremely high specialized technical barriers, which are environmental protection equipment operation and maintenance and third-party carbon verification, the cost of cultivating purely technical green talent in-house far exceeds the relevant market price. Consequently, firms tend to outsource these “purely technical” or “end-of-pipe” tasks to specialized third-party energy-saving and emission-reduction service providers. This strategy implies that regulated firms’ own internal demand for purely technical green positions will not rise significantly. The third strategy is task embedding, which, under current Chinese situations, offers the lowest organizational change cost and the greatest organizational agility. Rather than creating dedicated green positions on a large scale, firms revise the responsibility scope and performance criteria of existing positions, distributing green tasks across the routine workload of traditional roles. For example,

traditional procurement managers are required to establish green and low-carbon supply chains; traditional production line engineers are tasked with meeting dual-control targets for energy consumption; and administrative staff are expected to additionally undertake ESG compliance reporting.

It should be noted that the recruitment data used in this paper can only capture the recruiting behavior of regulated firms themselves, i.e., corresponding to the first and third strategies described above; the labor demand involved in the outsourcing strategy occurs within third-party service firms rather than within the emission-regulated firms, and thus lies outside the direct observation scope of this paper.

Building on this reasoning, we propose the following core hypothesis: under China's current institutional and market environment, firms confronted with the carbon market shock are more likely to adopt task embedding than the alternatives. Three considerations support this view. First, Chinese firms, especially non-state-owned enterprises, face intense market competition and stringent cost constraints and are reluctant to expand dedicated positions on a large scale solely for compliance purposes. Second, international experience has already shown that the supply of green-skilled talent generally lags behind demand, and China's green talent cultivation and supply system suffers from a similar supply–demand mismatch, making the search costs for recruiting specialized environmental experts relatively high. Third, many of the green tasks imposed by the carbon market do not in themselves require full-time professional environmental personnel but can be completed as supplementary responsibilities of existing management and technical positions, such as carbon emissions data reporting, energy consumption ledger compilation, environmental reporting submissions, etc. Hybrid positions that integrate green skill requirements onto traditional roles, or in other words, task-embedding green positions, offer firms the best route for absorbing the costs of environmental regulation.

Consistent with this hypothesis, in response to the carbon market shock the overall share of green jobs at the firm level should rise significantly, but the rise should display pronounced structural asymmetry. It will not stem from the expansion of purely technical or dedicated managerial green positions; rather, it will be driven by the emergence of task-embedding green positions that combine traditional functions with green compliance tasks. We interpret this restructuring path as a plausible mechanism, consistent with organizational agility and with cost minimization under carbon cost constraints. We formalize this core hypothesis into the following three testable hypotheses, which structure the empirical analysis that follows.

H1. *Coverage by the national carbon market is associated with a significant increase in the firm-level share of green jobs.*

H2. *This increase operates through task embedding rather than by internal specialization. Specifically: (H2a) the share of dedicated compliance-management positions does not expand and may decline; (H2b) the share of purely technical green positions does not rise significantly, consistent with outsourcing of specialized tasks; and (H2c) the share of hybrid task-embedding positions rises significantly and accounts for the bulk of the overall increase.*

H3. *The association is stronger for firms that face higher marginal compliance pressure and possess greater organizational flexibility, namely non-state-owned enterprises and firms in the eastern region, and is weaker or absent for state-owned enterprises and firms in central and western regions.*

3. Data Sources, Variable Definitions and Empirical Strategy

3.1. Data Sources

The empirical analysis in this paper combines two types of microdata. The first is firm-level recruitment data from Zhilian Zhaopin, one of China's leading comprehensive online recruitment platforms. This platform spans recruitment activities across the vast majority of industries and regions, and its job posting information is highly representative of A-share listed companies. The dataset includes over 13 million job posting records posted on the platform between 2016 and 2024, containing fields such as job title, job category, educational requirements, work experience requirements, salary range, and city of work location. The value of using online recruitment data to study the labor market is well established in relevant research, the key advantage of which lies in its ability to capture firms' timely hiring intentions and shifts in demand for specific skills [26,27]. Compared with traditional stock indicators such as "total number of employees," recruitment data can more accurately reflect firms' rapid organizational adjustments in response to policy shocks, making it particularly suitable for examining changes at the level of job structure. The second source is financial data on Chinese A-share listed companies drawn from the CSMAR database, including information on total assets, asset–liability ratio, net profit margin, year of establishment, net fixed assets, the nature of ultimate controller, industry classification, and stock code. We merge the Zhilian Zhaopin records with the firm financial data using firm stock codes and supplement the matching using firm location, and obtain an unbalanced panel dataset at the firm–city–year level.

Before estimation, the following cleaning procedures of the initial samples were implemented: (1) excluding samples of firms in the financial industry; (2) excluding ST and *ST firms; (3) excluding observations with missing values for key financial variables; (4) excluding observations in the recruitment data where the work city is missing or cannot be matched to the prefecture-level city level, to preserve the integrity of the firm–city–year panel structure; and (5) excluding firms that never posted any recruitment information during the sample period. In addition, to mitigate the impact of extreme values on the regression results, all continuous financial variables were winsorized at the 1st and 99th percentiles. After the above cleaning and winsorization, we obtain an unbalanced panel dataset at the firm–city–year level spanning 297 prefecture-level cities and 3665 A-share listed companies. In the effective sample of the baseline regression, the treatment group (emission-regulated enterprises covered by the national carbon market) comprises 136 firms, and the control group (non-regulated enterprises) contains 3559 firms.

3.2. Core Variable Definitions

- Dependent variable: share of green jobs

Our main lens on structural change in the labor market is the effect of the national carbon market on firms' share of green jobs. The green job share for firm i in city c in year t is defined as the number of green job postings released by the firm in that year divided by the total number of job postings released by the same firm in the same year. We identify green jobs by checking whether posting descriptions contain keywords related to environmental protection, energy conservation, emission reduction, carbon management, ESG, and the like. Table 1 shows that the sample mean of the firm-level green job share is 0.043, with a standard deviation of 0.176 and a median of zero. This distribution pattern indicates that the majority of firms did not post any green job postings during the sample period, and that green job demand is concentrated in a small number of firms directly affected by the carbon market policy. The policy effects identified in this paper thus mainly stem from changes in the green job share of these firms before and after the carbon market shock.

- Core explanatory variable: the unified national carbon market policy

The national carbon market officially launched trading in 2021, and this year serves as the policy shock timing for the first batch of emission-regulated enterprises; for enterprises included in subsequent years, we treat each firm's year of admission as its individual policy shock. Considering that it takes time for the carbon market policy to go from formal implementation to actually influencing firms' hiring decisions and job structure adjustments—involving a series of links such as information transmission, strategic decision-making, and organizational implementation, resulting in a transmission lag, we use the one-period-lagged interaction term as the core explanatory variable in the baseline regression. Specifically, DID_lag1 is built from two binary variables. The first is the treatment group dummy variable $Treat_i$, which equals 1 if firm i is included in the emission-regulated list of the national carbon emissions trading market, and 0 otherwise. The second is the post-policy dummy variable $Post_t$, which equals 1 if year t is on or after the year in which firm i was included in the carbon market, and 0 otherwise. Their interaction DID_{it} , which equals $Treat_i \times Post_t$, constitutes the standard difference-in-differences treatment variable. Building on this, this paper lags the interaction term by one period, i.e., DID_lag1_{it} equals $DID_{i,t-1}$, to serve as the core explanatory variable in the baseline regression.

Control variables. A set of firm-level characteristics that affect firms' recruitment behavior and green job allocation are controlled. Following the existing literature, the following control variables are introduced: firm size, asset–liability ratio, return on total assets, firm age, and capital intensity. Specifically, firm size is defined as the natural logarithm of total assets, firm age is measured as the natural logarithm of the number of years since the firm's founding, and capital intensity is measured as the natural logarithm of net fixed assets. Table 1 reports descriptive statistics of all main variables.

Table 1. Descriptive statistics of the main variables.

	Count	Mean	Std.	Min	p50	Max
Green_Ratio	56,340	0.043	0.176	0.000	0.000	1.000
DID_lag1	17,775	0.002	0.039	0.000	0.000	1.000
Firm size (lnSize)	52,258	22.751	1.637	19.942	22.517	28.042
Leverage ratio (Lev)	52,258	0.417	0.213	0.051	0.397	0.910
ROA	52,258	0.044	0.064	−0.195	0.040	0.234
Firm age (lnAge)	52,258	3.046	0.300	2.197	3.091	3.664
Capital intensity (lnCapInt)	51,661	12.217	1.188	8.246	12.421	14.668

Notes: Control variables at the firm level include firm size, leverage ratio of the firm, ROA of the firm, firm age, capital intensity of the firm. Precisely, the size of a firm (Size) is reflected by the total assets of the firm. ROA is calculated by net income divided by total assets. The age of a firm (Age) is measured by the current year minus the year of establishment of the firm. The capital intensity (lnCapInt) is reflected by the net fixed assets of the firm. In particular, firm size, firm age, and capital intensity are all measured using their natural logarithms.

3.3. Empirical Strategy

This study adopts a quasi-experimental research design and identifies the causal effect of carbon market regulation using a staggered difference-in-differences (DID) strategy. The launch of China's national carbon market provides an exogenous policy shock: firms in the covered sectors are assigned to the treatment group, while comparable firms outside the covered sectors form the control group. Because coverage is determined by rules set at the sector level rather than by the labor decisions of individual firms, this setting approximates a natural experiment and allows us to interpret the estimated coefficients as the effect of carbon market regulation on the structure of jobs within firms, conditional on the identifying assumptions set out below. The study is therefore observational rather than experimental, and it draws on the firm–city–year panel described in Section 3.1. All

empirical analyses in this paper were conducted using Stata/MP 18.0 (StataCorp LLC, College Station, TX, USA).

3.3.1. Model Specification

Using the launch of the unified national carbon emissions trading market as a policy shock, a difference-in-differences model is conducted to examine the association between the carbon emissions trading policy on firms' share of green jobs [28]. The baseline regression model is specified as follows:

$$Green_Ratio_{ict} = \alpha + \beta \cdot DID_lag1_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{ict} \quad (1)$$

where i , c , and t represent firm, city, and year, respectively. The dependent variable $Green_Ratio_{ict}$ is the share of green jobs of firm i in city c in year t . The core explanatory variable DID_lag1_{it} is the difference-in-differences variable indicating whether the firm is covered by the national carbon market policy in the current year. It equals the interaction term between the treatment group dummy $Treat_i$ and the post-policy dummy $Post_{t-1}$, taking the value 1 if firm i is regulated and year $t - 1$ already falls within the policy implementation period, and 0 otherwise. The coefficient β is the core parameter of interest in this paper, reflecting the average treatment effect of the carbon market shock on firms' share of green jobs. X_{it} is a vector of firm-level control variables. μ_i denotes firm–city joint fixed effects, which control for time-invariant firm and city characteristics, such as corporate culture and local industrial endowments. λ_t denotes year fixed effects, which control for macro-level trends affecting firms, such as business cycles and national environmental policy trends. ε_{ict} is the idiosyncratic error term.

It should be noted that after the national carbon emissions trading market was officially launched in 2021, the first batch covered 2162 emission-regulated enterprises in the power sector. In the A-share listed company sample used in this study, the treatment group of firms covered by the carbon market comprises 136 firms, of which 106 were included in the first batch and 30 were gradually included in subsequent years; thus, a small number of cases with staggered treatment timing exist within the treatment group. Accordingly, we treat each firm's year of admission as its individual policy shock and construct DID_lag1 on that basis. Since subsequently admitted firms account for only approximately 22% of the treatment group and their inclusion years are concentrated between 2021 and 2023—leaving a limited temporal difference from the first batch—the heterogeneous treatment effect bias documented in recent literature is unlikely to pose a significant concern under the sample structure of this paper [29].

3.3.2. Parallel Trends and the Identification Assumption

The consistency of the difference-in-differences estimator rests on the parallel trends' assumption: prior to the carbon market shock, the share of green jobs in the treatment and control groups should exhibit parallel time trends [30]. We test this assumption with an event-study specification:

$$Green_Ratio_{ict} = \alpha + \sum_{k \neq -1} \beta_k \cdot Treat_i \times 1(t = t_0 + k) + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{ict} \quad (2)$$

where t_0 denotes the year of the policy shock, k indexes the event time relative to the policy shock, with $k = -1$ designated as the base period [31]. If the parallel trends' assumption holds, the coefficients β_k for pre-policy periods ($k < 0$) should not differ significantly from zero. Test results are reported in Section 4.

3.3.3. Heterogeneity Analysis Strategy

Furthermore, to examine the heterogeneous effects of the carbon market across different firm characteristics, subsample regressions are run by firm ownership type and geographic location and, on the full sample, the interaction term between DID_lag1_{it} and the grouping variable is introduced. The statistical reliability of between-group differences is assessed via the significance of the interaction coefficient, and the results are reported in Section 5 [32,33].

4. Baseline Results and Robustness

4.1. Baseline Regression Results

Table 2 reports estimates of the carbon trading policy's effect on firms' green job share based on the baseline specification. Column (1) includes only the core regressor, firm-city fixed effects, and year fixed effects. Even without firm-level controls, the coefficient on $ETS \times Post$ (one-period lag) is 0.0462 and significant at the 1% level, an initial indication that carbon trading raises firms' green job share. In column (2), adding firm size and the asset-liability ratio nudges the coefficient up to 0.0486, with no change in significance. Column (3) adds the remaining firm-level controls—return on total assets, firm age, and capital intensity—and the coefficient remains significantly positive. To absorb potentially divergent green-development trends between the eastern coastal region and the central and western regions, column (4) adds a $region \times year$ trend on top of the baseline. The core coefficient remains positive and significant, while the $region \times year$ trend itself is insignificant, indicating that regional trend differences are not driving the baseline result. We also estimate specifications that include industry-by-year fixed effects. Because the national carbon market initially covered only the power sector, the treatment indicator is, by construction, an exact function of the (power) industry; a full set of industry-by-year fixed effects therefore spans the same variation as the treatment interaction, and the two are collinear. Once these fixed effects are included, no within-industry-by-year variation remains from which the treatment coefficient can be separately identified, and the coefficient consequently becomes insignificant. This loss of significance reflects over-control, in which the fixed effects absorb the policy variation itself, rather than the absence of a policy effect; the same constraint would arise under alternative estimators that rely on the same single-industry treatment. We regard this as an intrinsic feature of identifying a single-industry policy, and we discuss in Section 7 how the expansion of the national market to additional high-emission sectors will provide the cross-industry variation needed for a more demanding test. Further details are provided in Appendix A.

Regarding standard errors, they are clustered at the industry level to account for error correlation among firms within the same industry [34]. This choice reflects the institutional fact that carbon market policy delineates regulated boundaries by industry: firms in the same industry face identical allowance allocation rules and a common carbon price, and the random shocks to their hiring decisions are likely correlated within industries.

The results above show that the carbon emissions trading market significantly raises firms' green job share. Taking column (3) as the baseline, inclusion in the national carbon market raises the green job share of regulated firms by roughly 4.7 percentage points. Given that the sample mean of the green job share is only 4.3%, this is an increase of about 110% relative to the mean. The median green job share is zero, meaning that more than half of sample firms posted no green jobs at all during the sample period. Against that backdrop, an increase of 4.7 percentage points indicates that the policy shock has a substantive effect on the green job structure of regulated firms.

Table 2. Baseline results.

	(1)	(2)	(3)	(4)
ETS $\times$ Post	0.0462 *** (0.003)	0.0486 *** (0.004)	0.0475 *** (0.006)	0.0475 *** (0.006)
lnSize		0.0004 (0.007)	0.0008 (0.008)	0.0008 (0.008)
Lev		−0.0248 (0.031)	−0.0303 (0.029)	−0.0302 (0.030)
ROA			−0.0271 (0.043)	−0.0272 (0.043)
lnAge			0.0509 (0.080)	0.0503 (0.080)
lnCapInt			−0.0002 (0.005)	−0.0001 (0.005)
Region $\times$ Year Trend				−0.0006 (0.003)
<i>N</i>	11,111	11,098	11,030	11,030
<i>R</i> ²	0.681	0.681	0.684	0.684

Note: The standard errors of robustness clustered to the industry level are in parentheses, and *, **, *** respectively indicate significance levels of 10%, 5% and 1%. Firm fixed effects, city fixed effects, and year fixed effects have been controlled.

4.2. Robustness Tests

To ensure the reliability of the baseline regression results, robustness tests in four dimensions are conducted.

1. Parallel Trends Test

As noted above, the consistency of the DID estimator rests on the validity of the parallel trends' assumption. The assumption is tested using an event study approach, taking the year before the policy shock as the base period and tracing changes in firms' green job share around the shock. Figure 1 reports the results.

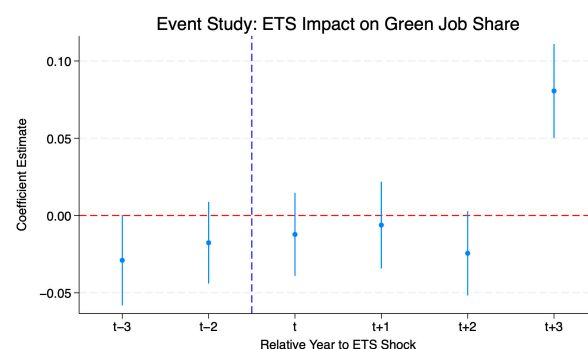


Figure 1. Test for parallel trends. The dots represent the event-study coefficient estimates, and the vertical bars denote the 95% confidence intervals. The red dashed horizontal line marks zero, and the blue dashed vertical line indicates the timing of the carbon market shock. The year before the shock ($t - 1$) is the omitted base period.

Before the carbon market launch, no significant difference in green job share emerges between the treatment and control groups, supporting the parallel trends assumption and lending credibility to our identification. After implementation, the effect displays a pronounced lag: in the first two years following the shock the coefficient is positive but statistically insignificant, and from the third year onward it rises sharply and becomes significant. This dynamic pattern reflects the gradual pace of within-firm organizational adjustment. From the launch of the carbon market policy to the completion of the first com-

pliance cycle takes time, and once firms perceive policy pressure, the path from assessing compliance costs, to adjusting internal job configurations, to translating those adjustments into hiring behavior runs through several layers of organizational decision-making. This lagged pattern is consistent with the gradual nature of organizational adjustment. The fact that the carbon market's positive effect on the green job share concentrates from the third year onward speaks directly to the gradual nature of the organizational change implied by the task-embedding mechanism.

2. Placebo Test

To rule out the influence of unobserved variables such as omitted variables, a placebo test is performed by randomizing treatment along both the firm and time dimensions over 500 iterations. In each iteration, roughly 3% of sample firms which match the share of the actual treatment group are randomly drawn as a “pseudo-treatment group”, a firm-specific pseudo-shock year is randomly assigned, and a placebo interaction is constructed accordingly. Figure 2 presents the distribution of the estimated coefficients and p -values obtained from these 500 random regressions. It can be observed that the mean of the regression coefficients is distributed around zero, and the vast majority of p -values are far above 0.10. These findings indicate that the significant impact of the national carbon market on firms' share of green jobs cannot be attributed to other unobservable factors.

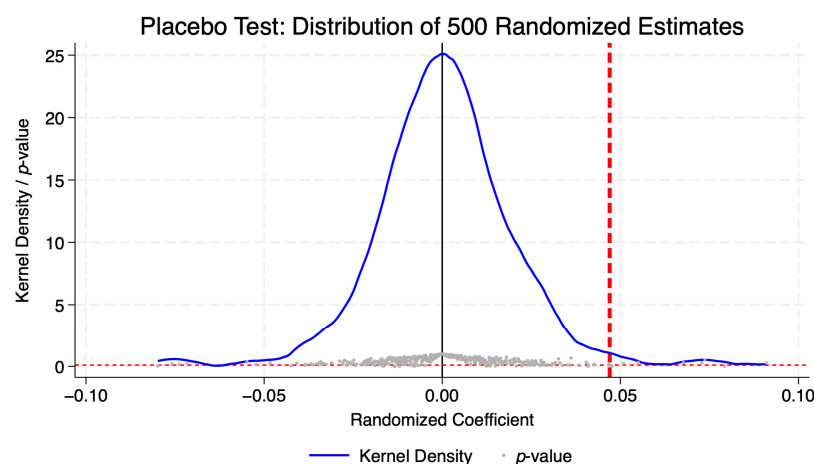


Figure 2. Placebo test. The blue curve is the kernel density of the coefficients from 500 randomized (placebo) regressions, and the grey circles are their corresponding p -values. The black solid vertical line marks zero, the red dashed vertical line indicates the true estimated coefficient (0.047), and the red horizontal dashed line marks the 0.10 significance threshold.

3. Ruling Out Interference from Contemporaneous Policies

To rule out the confounding effects of other environmental policies implemented concurrently on the net effect of the carbon market, the influence of such policies is controlled to test whether the rise in firms' green job share is genuinely attributable to the carbon emissions trading policy. Based on this, we add an interaction term between the concurrent Low-Carbon City Pilot and a year trend ($LCCP \times Year\ Trend$) to capture any gradual, time-varying impact that the Low-Carbon City Pilot exerts. The results are reported in Table 3. Column (1) presents the baseline regression results, while column (2) reports the results after incorporating the LCCP time trend control. It can be found that the coefficient of $LCCP \times Year\ Trend$ is 0.0001 and statistically insignificant, suggesting that the Low-Carbon City Pilot policy did not have a significant independent effect on firms' green job share. At the same time, after adding the LCCP time trend, the coefficient and significance of the core explanatory variable $ETS \times Post$ remain virtually identical to the baseline regression. This further supports the conclusion that the carbon emissions trading market is the primary

driver of the increase in firms' green job share, rather than the confounding effects of other contemporaneous environmental policies.

Table 3. Robustness test (Exclude the influence of environmental regulation policy of Low-Carbon City Pilot in the same period.).

	(1) Baseline	(2) Control LCCP
ETS $\times$ Post	0.0475 *** (0.006)	0.0475 *** (0.006)
LCCP $\times$ Year Trend		0.0001 (0.002)
Controls	Yes	Yes
N	11,030	11,030
R ²	0.684	0.684

Note: The standard errors of robustness clustered to the industry level are in parentheses, and *, **, *** respectively indicate significance levels of 10%, 5% and 1%. Firm fixed effects, city fixed effects, and year fixed effects have been controlled.

4. Robustness to the Zero-Inflated Dependent Variable

A further concern is that the dependent variable, the green job share, equals zero for about 89% of firm-year observations. To address this high frequency of zeros, we re-estimate the baseline model using a Poisson pseudo-maximum-likelihood (PPML) estimator, which is appropriate for a non-negative dependent variable with many zeros and does not require the outcome to be logarithmically transformed. As reported in Appendix Table A1, the coefficient on the carbon-market variable remains positive and significant at the 10% level, preserving the sign and direction of the baseline estimate; the somewhat lower precision relative to the linear specification is consistent with the limited number of treated firm-years and the conservative clustering of standard errors at the industry level. The result indicates that our finding is not an artifact of the zero-heavy distribution of the dependent variable.

5. Further Analysis: Mechanism and Heterogeneity

5.1. Mechanism Test

The analysis above establishes that the launch of the national carbon market substantially raised firms' share of green jobs. But what changes inside the firm's organizational structure lie behind this effect? Did firms respond to higher compliance costs by pursuing front-end technological innovation and thus raising their demand for highly specialized technical talent? Or did they instead strengthen end-of-pipe compliance management and raise their demand for management-oriented green skills?

To unpack the transmission mechanism, we further partition green jobs into three categories: compliance management positions, encompassing tasks such as carbon accounting, ESG compliance, and environmental auditing; technical specialist positions, such as environmental equipment R&D, energy conservation engineers, and desulfurization and denitrification operators; and hybrid task-embedding positions, that is, traditional positions to which green compliance tasks have been added. We use each category's share of total job postings as the dependent variable in separate regressions. It bears emphasis that the three categories do not exhaustively partition total green jobs, so the three coefficients should not be read as an additive decomposition; each constitutes an independent mechanism test [35]. The results are reported in Table 4.

Table 4. The mechanism of ETS on green job ratio.

	(1) Admin/Compliance	(2) Pure Technical	(3) Integrated
ETS × Post	−0.0966 *** (0.010)	0.0126 (0.021)	0.0443 *** (0.005)
Controls	Yes	Yes	Yes
N	10,840	10,840	10,840
R ²	0.556	0.726	0.627

Note: The standard errors of robustness clustered to the industry level are in parentheses, and *, **, *** respectively indicate significance levels of 10%, 5% and 1%. Firm fixed effects, city fixed effects, and year fixed effects have been controlled.

Table 4 reports the results of the three sets of regressions. Column (1) shows that the impact of the carbon market shock on the share of compliance management positions is significantly negative. This finding indicates that after ETS implementation, firms not only failed to expand environmental management positions but instead substantially reduced such positions. This is consistent with the transaction cost theory prediction in institutional economics: before the carbon market shock, the environmental management positions established by some firms primarily performed a “symbolic compliance” function targeting regulatory agencies, making limited contributions to actual emission reductions. Once the carbon market converted carbon emissions into quantifiable financial costs, firms found that maintaining these high-cost, low-effectiveness dedicated positions was no longer cost-effective, and thus adopted more flexible organizational response strategies.

Column (2) shows that the coefficient of the carbon market shock on the share of technical specialist positions is 0.0126, but statistically insignificant. This likely reflects firms’ propensity to outsource when faced with end-of-pipe treatment demands. Since firms may not originally possess the relevant professional background, establishing new environmental departments and positions to meet emission reduction needs would incur higher costs and information costs. They therefore tend to outsource highly specialized technical tasks such as desulfurization, denitrification, and waste gas treatment directly to third-party environmental service providers. This finding aligns with the rapid growth of China’s environmental services industry in recent years.

Column (3) identifies the true source of the increase in firms’ green job share. The carbon market shock has a statistically significant positive effect on the share of hybrid task-embedding positions, with a coefficient nearly identical to that of the baseline regression. The overall rise in the green job share is therefore driven almost entirely by the expansion of these hybrid roles.

Taken together, the three sets of estimates trace out the organizational adjustment landscape that firms produce in response to the carbon market. These patterns are consistent with an organizational adjustment in which firms do not rely on a capital-intensive expansion strategy based on the large-scale establishment of dedicated environmental departments. Rather, the data are consistent with a high degree of organizational agility: a declining share of “symbolic” compliance positions, no significant expansion of specialized technical positions consistent with the outsourcing of such services, and a rising share of positions that embed green emission reduction tasks into existing roles. We label this organizational phenomenon task embedding: by layering green tasks such as carbon management and energy conservation onto traditional positions in production management, administrative operations, financial accounting, and similar functions, firms meet the compliance requirements of the carbon market at the lowest organizational change cost, which in turn drives the substantive rise in their green job share. This pattern indicates that the carbon market reshapes the composition of employment within firms rather than its

overall level, and it illustrates how the task allocation framework operates in the context of environmental policy.

This pattern of task embedding is also visible in the way regulated firms have actually organized their carbon-related work in practice. In the power sector, for instance, most plants have not established a standalone carbon management position; instead, carbon emissions data management is led by the existing environmental department, while allowance trading is handled by the business or operations department, with these responsibilities absorbed by staff already in post. More broadly, industry observers note that the great majority of those now performing carbon management work within firms have moved into it from adjacent functions such as energy and environmental management, rather than being hired into newly created dedicated roles. This gap between a rapidly rising demand for carbon-related work and the limited creation of dedicated carbon positions is consistent with our central argument: firms meet new compliance tasks primarily by embedding them into existing jobs. We emphasize that our data capture the task content of advertised positions rather than firms' internal decision-making processes. We therefore interpret task embedding as a plausible mechanism that is consistent with the observed changes in job structure, rather than as direct evidence that firms deliberately pursue such a strategy.

5.2. Heterogeneity Analysis

The baseline regression demonstrates a statistically significant positive impact of the carbon market shock on firms' share of green jobs. However, differences in firm characteristics and external environments may result in heterogeneous firm responses to the policy shock, which may affect the generalizability of our findings. Heterogeneity tests along two dimensions are performed, which included ownership type and geographic location. We further assess the statistical significance of cross-group differences using triple interaction term specifications. Table 5 reports the full results of the heterogeneity analysis, with columns (1) and (2) presenting results for ownership type, and columns (3) and (4) showing results by geographic location, with the triple-interaction tests reported in the table notes.

Table 5. Heterogeneity by ownership and region.

	(1) SOE	(2) Non-SOE	(3) Eastern	(4) Central/Western
ETS × Post	−0.0443 (0.056)	0.1018 *** (0.007)	0.1032 *** (0.006)	−0.0696 ** (0.032)
Controls	Yes	Yes	Yes	Yes
<i>N</i>	1803	8669	6688	4342
<i>R</i> ²	0.695	0.679	0.682	0.690

Note: The standard errors of robustness clustered to the industry level are in parentheses, and *, **, *** respectively indicate significance levels of 10%, 5% and 1%. Firm fixed effects, city fixed effects, and year fixed effects have been controlled. The difference tests results of triple interaction ($DID \times Group$) are as follows: The coefficient of $DID_lag1 \times SOE$ is -0.1702^{***} , The coefficient of $DID_lag1 \times Eastern$ is 0.1687^{***} . Industry heterogeneity is not analyzed because all treated observations fall within heavy-polluting industries.

1. Ownership Heterogeneity

To test whether the carbon market effect varies with firm ownership, we split the full sample into state-owned (SOE) and non-state-owned (non-SOE) subsamples and estimate them separately, with results in columns (1) and (2). The green job share rises significantly for non-SOEs, while the coefficient for SOEs is insignificant. To gauge whether this between-group gap is statistically meaningful, we add a triple-interaction term between DID_lag1 and the SOE dummy in a supplementary regression, reported in the table notes. The coefficient on $DID_lag1 \times SOE$ in this supplementary regression is -0.1702 , significant

at the 1% level, indicating that the policy effect for SOEs is 0.1702 lower than that for non-SOEs and that this gap is statistically robust.

Under the carbon market shock, non-SOEs actively advance the green job transformation, while SOEs exhibit no substantive response. Two factors help explain this. On the one hand, SOEs' allowance allocation method and policy enforcement intensity may expose them to relatively lower marginal compliance pressure. In the first compliance cycle, the national carbon market implemented a 100% free benchmark allocation method, with allowance quantities adjusted in proportion to firms' output. Large state-owned power groups generally operate advanced equipment; their unit product emission intensity is close to or below the industry benchmark, the gap between actual emissions and free allowances is narrow, and their marginal compliance costs are limited. Additionally, during the actual implementation process of the first compliance cycle, regulatory authorities adopted relatively lenient negotiated enforcement toward large state-owned power generation groups, further attenuating the policy pressure signals received by SOEs. On the other hand, SOEs are constrained by administrative hierarchy approval and staffing management systems, making the flexibility of job structure adjustments far lower than that of private enterprises, which hinders their ability to rapidly implement the task embedding strategy [36]. In contrast, private enterprises are more sensitive to the cost signals released by the carbon market and possess more flexible organizational structures, enabling them to quickly embed green compliance tasks into the responsibility lists of traditional positions.

2. Regional Heterogeneity

Columns (3) and (4) of Table 5 split the sample into the eastern coastal region and the central and western regions. Column (3) shows that the carbon market shock significantly increases the green job share of eastern firms, significant at the 1% level. Column (4) shows that the policy's impact on central and western firms is significantly negative, indicating that the carbon market shock instead led to a decline in the share of green jobs for central and western firms. The triple interaction term test in the notes to Table 5 confirms the statistical significance of this divergence. The estimated coefficient of $DID_lag1 \times Eastern$ is 0.1687, significant at the 1% level, indicating that the policy effect in the eastern region is approximately 16.9 percentage points higher than that in the central and western regions, and this difference is statistically significant.

This regional divergence can be explained along four dimensions. First, the two regions differ in the availability of green skills. The eastern coastal region has a larger pool of workers with green expertise and a more mature environmental service market, so that firms there can more readily recruit, or redeploy existing staff into, composite roles that combine conventional functions with green compliance tasks. In the central and western regions, by contrast, the supply of green-skilled labor is thinner, which raises the cost of embedding green tasks into existing positions and limits the scope for this kind of adjustment.

Second, the two regions differ in environmental governance. Environmental regulation tends to be enforced more strictly in the east, and the price signal of the carbon market is transmitted more effectively there, so eastern firms face stronger and more credible compliance pressure. Weaker and less consistent enforcement in the central and western regions reduces the incentive for firms to reorganize their workforce in response to the carbon market, and some firms may even compress environment-related investment under the pressure of rising carbon costs.

Third, labor mobility reinforces this gap. The eastern region's higher wages and denser labor markets attract green-skilled workers from across the country, including from the central and western regions, which deepens the eastern talent pool while draining it elsewhere.

This mobility makes task embedding easier to sustain in the east and harder in interior regions, where firms struggle both to attract and to retain workers with green competencies.

Fourth, the regions differ in industrial structure. Eastern economies are more oriented toward services and higher value-added manufacturing, where green tasks are more readily integrated into existing professional and managerial roles. The central and western regions rely more heavily on resource-intensive and traditional heavy industries, in which compliance is more likely to be met through physical abatement or outsourcing than through the redefinition of job content, leaving less room for task embedding to take hold.

Taken together, these four factors suggest that the carbon market does not operate uniformly across space. Where green skills are abundant, enforcement is credible, labor markets are deep, and the industrial mix is favorable, the carbon market encourages firms to embed green tasks into their workforce; where these conditions are absent, the same policy may instead be associated with a relative contraction of green hiring.

6. Discussion

6.1. Comparison with International Experience

Our findings also speak to the broader international literature on green transition and labor restructuring, and they suggest that the Chinese experience differs from the European one in instructive ways. The two systems differ markedly in how compliance costs reach the firm. In the European Union Emissions Trading System, auctioning has been the main method of allowance distribution, accounting for a majority of the cap, and electricity generators have been required to purchase most of their allowances since 2013. By contrast, China's national carbon market in its first compliance cycle allocated allowances entirely for free, using an output-based intensity benchmark. Under full auctioning, carbon costs enter the firm as a direct and salient cash outlay, which tends to encourage technological abatement and the creation of specialized functions. Under free, output-based allocation, by contrast, the marginal cost of compliance is more muted and is felt primarily as an administrative and reporting burden rather than as a large direct expense.

This difference in institutional design helps explain why task embedding may be particularly characteristic of Chinese firms at this stage. When the immediate obligation created by the carbon market is to measure, report, and manage emissions rather than to pay a large allowance bill, the most cost-effective response is to add these compliance tasks to existing roles rather than to build dedicated environmental departments. China's institutional environment reinforces this tendency: the dominance of state ownership in regulated sectors, the relatively gradual and sector-by-sector expansion of market coverage, and a labor market in which firms retain considerable discretion over the task content of jobs together favor incremental, within-firm reorganization over large-scale restructuring of the workforce. Task embedding can thus be understood as a response shaped by the specific stage and design of China's carbon market, and we would expect the balance between embedding and specialization to shift as allocation tightens and auctioning is gradually introduced.

6.2. Theoretical Contributions

Building on this comparison, our study makes three theoretical contributions. First, it shifts the analytical focus of the literature on environmental regulation and employment from the quantity of labor to its internal structure: rather than asking whether carbon pricing raises or lowers the total number of workers a firm employs, we ask how it reshapes the composition of jobs within the firm, and we show that substantial structural adjustment can take place even when aggregate employment is little changed. Second, the study extends the task allocation framework to the setting of environmental policy, treating

the carbon market as an exogenous shock that adds green compliance tasks to a firm's existing set of tasks and tracing how this shock is transmitted into observable changes in the structure and skill content of jobs. Third, it identifies task embedding as the central mechanism through which firms accommodate carbon market regulation, which enriches our understanding of how environmental regulation translates into firm-level labor demand and provides a conceptual basis for future research on the organizational channels of the green transition.

7. Conclusions

To meet the severe challenges of climate change and advance green and high-quality development strategies, China has achieved significant emission reduction outcomes since launching its national carbon emissions trading market in 2021. As a major external shock, the carbon emissions trading policy inevitably reshapes firm behavior, and the resulting rise in pollution abatement costs leaves traces in firms' hiring records. Against the macro backdrop of a tight labor market, the intrinsic link between the emission reduction dividends of environmental regulation and employment restructuring at the firm level has become a key focus of both academia and policymakers. Building on the extensive prior discussion of aggregate employment effects, we have asked instead how carbon trading shapes the quality and structure of employment within firms. Using micro-level recruitment data and financial data of Chinese A-share listed companies from 2016 to 2024 and employing a difference-in-differences approach, the effect of the national carbon emissions trading market on firms' green job structure and its underlying mechanism are investigated. Our central finding is that carbon trading significantly raises the green job share at the firm level. On average, being included in the national carbon market raises the share of green jobs in regulated firms by approximately 4.7 percentage points, which corresponds to approximately 110% of the sample mean. This result remains robust after a series of robustness tests, including parallel trends testing, placebo testing, and controlling for confounding effects of contemporaneous policies.

The heterogeneity analysis shows that responses vary sharply across firms. Unlike state-owned enterprises, private firms experience a significant increase in the share of green jobs. Moreover, the impact of the carbon market on firms' share of green jobs exhibits significant regional disparities: the effect is significantly positive in the eastern coastal region, while the share of green jobs declines significantly for firms in the central and western regions. These results indicate that the effectiveness of the carbon emissions trading market policy cannot be generalized and is also contingent on policy enforcement intensity, firm organizational flexibility, and the availability of supporting policies.

The mechanism analysis pinpoints the source of the rise in green jobs. The results reveal that the driving force behind the growth in green jobs does not stem from the establishment of new dedicated environmental departments, but rather from task embedding. Under the carbon market shock, the share of compliance management positions declines significantly, technical specialist positions show no significant change, while the share of hybrid task-embedding positions increases significantly, with a coefficient almost identical to the overall effect. This indicates that when faced with carbon market compliance pressure, firms do not resort to costly measures such as creating environmental departments; instead, they embed green tasks such as carbon management and energy conservation and emission reduction into traditional positions in production management, administrative operations, and other functions, thereby meeting compliance requirements at the lowest organizational adjustment cost.

From a practical standpoint, the findings carry three implications. First, the green talent cultivation system should be aligned with the practical characteristics of task embed-

ding. The findings of this paper demonstrate that firms' actual demand for green human resources is not concentrated on dedicated environmental technicians, but rather leans more heavily toward composite talent who combine traditional business capabilities with green knowledge. Therefore, the curriculum design of vocational education and higher education should strengthen interdisciplinary integration, systematically embedding carbon management and environmental compliance modules into traditional disciplines such as business administration, financial accounting, and production operations, to better align with firms' actual talent demand. Second, attention should be paid to the regional disparities in the carbon market's labor market effects. Our finding shows that the share of green jobs in the central and western regions declines rather than rises, a phenomenon that suggests that the carbon market may exacerbate the inter-regional green development gap. As we accelerate the development of the national carbon emissions trading market, targeted green skills training subsidies and employment transition support should be provided to firms in the central and western regions, to advance the "just transition" agenda, reduce employment frictions, and enhance labor mobility across regions and industries. Third, the mechanism design of the carbon market policy and the carbon emission allowance allocation mechanism should be optimized to strengthen both the external constraints and internal incentives for emission-regulated enterprises, with a focus on enhancing the organizational responsiveness of state-owned enterprises within the carbon market. As the mainstay of key emission-regulated industries, the sluggish green transition of state-owned enterprises will constrain the overall policy effectiveness of the carbon market. It is therefore necessary to create space for the organizational adjustment of SOEs from the dimensions of performance evaluation mechanisms and position management systems.

This study has several limitations that also point to directions for future research. First, our evidence is based on online recruitment postings, which capture firms' advertised hiring intentions and the stated content of jobs rather than realized hires or internal job-redesign decisions. The task-embedding mechanism is thus an inference from the changing composition of postings, and confirming it with personnel records, internal job descriptions, or firm interviews would strengthen the interpretation. Second, the treatment group in the first compliance cycle is confined to the power sector, so the external validity of the estimates to other industries that the national carbon market will cover in the future remains to be tested as the market expands. Third, keyword-based identification, although transparent and replicable, can omit embedded green tasks expressed in non-standard language. Fourth, the sample period captures only the early years of the national market under predominantly free, output-based allocation; how firms' organizational responses evolve as allocation tightens and auctioning is introduced is an open and important question. Addressing these limitations, by drawing on multi-sector data, longer panels, and complementary qualitative evidence, would further test the generality of the task-embedding mechanism documented here.

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Abbreviations

The following abbreviations are used in this manuscript:

ETS	Emissions Trading System
CSMAR	China Stock Market and Accounting Research Database
O*NET	Occupational Information Network
ESG	Environmental, Social and Governance
ST	Special Treatment
ROA	Return On Assets
LCCP	Low-Carbon City Pilot
KPI	Key Performance Indicator
SOE	State-Owned Enterprise
DID	Difference-in-Differences
R&D	Research and Development

Appendix A

This paper also tests the regression results after incorporating industry $\times$ year interactive fixed effects. Since the national carbon market initially covered only the power sector, the treatment group firms are highly collinear with the industry dimension, and the industry $\times$ year fixed effects absorb the variation in the policy effect itself, causing the core coefficient to become insignificant. This constitutes an over-controlling problem rather than an absence of a policy effect. Similar identification constraints are commonly encountered in the DID literature that studies the shock of a single-industry policy.

Table A1. Robustness to the zero-inflated dependent variable: PPML estimation.

	Green Job Share (PPML)
ETS $\times$ Post	0.360 * (0.195)
Controls	Yes
Firm–city fixed effects	Yes
Year fixed effects	Yes
Observations	3585
Industry clusters	55
Pseudo R ²	0.231

Notes: The dependent variable is the firm-level green job share. The estimator is Poisson pseudo-maximum-likelihood (PPML), which is appropriate for a non-negative dependent variable with a high frequency of zeros. All specifications include firm–city and year fixed effects. Robust standard errors, clustered at the industry level, are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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