E3S Web of Conferences **236**, 02013 (2021) https://doi.org/10.1051/e3sconf/202123602013
*ICERSD 2020*

# Does R&D input matter the impact of financial resources allocation on green production in china's energy sectors

Zhengyu Qu[1], Tiansen Liu[1,2,3,*] and Yue Zhu[4]

[1]School of Economics and Management, Harbin Engineering University, Harbin, 150001, CHINA
[2]School of Social and Behavioral Sciences, Nanjing University, Nanjing, 210023, CHINA
[3]State Key Laboratory of Pollution Control and Resource Reuse, Nanjing University, Nanjing, 210023, CHINA
[4]School of Management, Harbin Institute of Technology, Harbin, 150001, CHINA

**Abstract.** Corporate financial resources are always a tool to support their greenization. This paper investigates whether R&D input inspires financial resources allocation to better promote green production in China's energy sectors because of their pillar status to national industrial layout, significant impacts on climate change, and distinctive governance structure. By investigating 254 firm-year observations of China's energy sectors, we find that their R&D input (including funds and personnel inputs) is at a low level, and it has not improved green production. While R&D input can help release the allocation pressure of financial resources (including asset impairment, shareholders equity, and tax structure) in green production and shows a robust role of the two R&D indicators. Our theoretical model helps directly link financial resources allocation and greenization, and empirical results suggest exploring more transmission paths to address cask effects of resources allocation for climate-friendly operations in heavy-polluting sectors especially in emerging markets.

## 1 Introduction

Globally, the fragile ecological environment in emerging markets is largely because of less climate-friendly production of heavy-polluting sectors. As a systematic project, green production characterizes that top managers use production modes with green features to reduce negative impacts of products/services life-cycle on natural environment based on greenization conceptions.

Energy sectors with heavy-polluting features are leading national economy structures in various ways, and their productivity also influences regional development. Thus they need more efforts to reduce possible risks in global energy-flow and imbalance of energy structure among different economies. What's more, energy sectors' technology frontier progress is often slower than other sectors, and their technology efficiency mainly relies on internal innovation. Thus it needs to evaluate energy sectors' greenization from the perspective of resources allocation, especially under resources constraints.

Recent literature showed that within the drivers of corporate greenization, resources allocation is usually seen as a key component, and financial resources play a substantial role in maintaining the coherence of corporate predetermined production plans and actual outputs. Financial performance and green behaviors were bridged, while few literature focused on how financial resources allocation efficiency as a challenge influences corporate greenization, and what tools can mitigate this unfavorable case. Overcoming this cask effect will help robustly establish the improvement paths for corporate greenization. What's more, prior studies separately examined the impact of resources allocation efficiency on innovation efficiency, and such innovation on green production. Inspired by this with the aim to expand the transmission path of resources misallocation to green production, we will clarify the moderating role of R&D input in the relationship between financial resources allocation and green production.

In doing so, we will address aforementioned knowledge gaps from following perspectives. First, we expand the theoretical link between corporate financial resources allocation and greenization. Different from prior studies that focused more on how resources misallocation influences economy-growth-relevant variables (e.g. real output and total factor productivity), we try to enrich outputs of such allocation to environmental spheres. Total factor productivity is suggested as a key driver of growth of industrial sectors, and following studies suggested involving pollutants emission as a new input factor. Further, recent viewpoints suggested bridging resources allocation efficiency and economy output with involving green features, in order to reduce the loss caused by less-efficient resources integration. Therefore, we start from financial resources and theoretically explores how their allocation evolves into green production. Second, we elaborate how R&D input moderates the relationship between financial resources allocation and green production, which helps show possible transmission paths in line with the key role of R&D in corporate production. Further, we reveal how China's energy firms improve responsible business by integrating resources allocation

---

[*] Corresponding author: tiansen0328@hrbeu.edu.cn

and R&D behaviors. It often needs to explore the way to mitigate possible unfavorable impacts of less-efficient resources allocation that may have key impacts on subsequent operations. Thus this paper explores how firms make R&D more schematized and valuable. Third, we also focus on a global concern around how R&D leads business behaviors with more green features. Recently, the prosperity of multinational corporations suggests organizing intensive R&D inputs to adapt to broader stakeholders' perceptions for corporate image under cross-cultural variations. The sustainability of China's energy firms may set a benchmark for other economies in mitigating misallocations of corporate internal resources via multi-paths. Overall, we will clarify how to improve heavy-polluting sectors' green production through proactively harmonizing the relevance of different antecedents.

## 2 Literature review

### 2.1 The theoretical backing bridging resources allocation and corporate greenization

It was recently suggested that exploring multi-links between resources allocation and green strategies can improve our understandings of how less-efficient allocation influences the climate-friendly production. For a broad range of industrial sectors especially whose production process is closely associated with traditional energies, internal resources allocation, resources misallocation will appear once their allocation deviates from the Pareto optimal state, and this misallocation may actually restrict corporate greenization improvement.

The neoclassical growth theory emphasizes the role of capital in industrial sectors' growth. Following studies further designed the context where technology progress and government involvement are lagging behind, and then mitigating resources restraint and pollutants emission was found to rely on the rise of resources allocation efficiency. For economies that carry out the strategy of giving priority to heavy-polluting sectors, they should invest more resources in technology progress. Meanwhile, the use efficiency of financial resources in heavy-polluting sectors is a key tool to achieve green economy growth.

Above research expansions inspire to explore more correction paths targeting at possible conflicts between resources input and corporate greenization in order to reduce the unnecessary cost when corporate marginal output is uncertain. Thus R&D can be seen as an opportunity that guides corporate production to focus on environmental spheres. For this reason, we progress theoretical analysis based on the view of traditional economy theories to emphasize the bridge role of R&D to financial resource allocation and green production.

### 2.2 The impact of financial resources allocation on green production

Although there are few studies focusing on the direct relationship between financial resources allocations and green production, dealing with the cask effect of resources misallocation is a key concern for corporate green production. Inspired by recent literature that bridged productivity and internal capital volatility, it can be seen that their relationship needs dynamic adjustments. Prior studies analyzed how financial resources lead to business eco-innovation, and measured this resource by obtained funds, including corporate internal funds, government awards, capability of using/adjusting funds. Besides traditional profitability indicators, slack/scarce fund is also a key financial resource because it determines whether firms have extra capabilities to deal with spheres beyond main business. Inspired by and financial data of China's energy sectors, we examine the impact of financial resources allocation from perspectives of asset management, shareholders equity, and tax structure because these indicators' implications for corporate greenization may have a disparity. We will following explain attributions of each financial resource.

#### *2.2.1 The impact of asset allocation on green production.*

As green production is a key target of advanced operations management, and the process of achieving greenization needs to inevitably deal with asset use efficiency. For heavy-polluting sectors, they usually take lots of asset management pressures from their large operations scale, long-lasting responsibility they need to take for environmental management, and an urgent work for technology frontier expansion and energy system optimization. Meanwhile, heavy-polluting sectors need a priority of policy, asset, and other relevant resources to deal with risks that have an occurrence probability than non-heavy-polluting sectors. Therefore, green production that covers economic and environmental spheres may need a high-quality asset structure, and this paper arranges the asset impairment loss to describe the level of corporate asset allocation efficiency. Given a broad state-owned attribute of China's energy sectors especially listed firms and dramatic volatility of asset-liability ratio in China's state-owned firms, assets misallocation may hinder green production of China's energy sectors. Thus we hypothesize:

Hypothesis 1. The allocation of asset impairment loss is negatively associated with green production.

#### *2.2.2 The impact of shareholders equity allocation on green production.*

Shareholders equity is also defined as net assets, and lower shareholders equity indicates a higher debt pressure. China's government has identified the possible risks from the ratio of debt and shareholders equity in manufacturing sectors, and the debt as a kind of available funds is a leverage for coordinating cost and revenue. For bulk commodities that energy sectors usually generate, a certain debt can help expand reproduction, and thus accelerate commodity circulation with the aid of timely funds input. This paper designs the equity multiplier (the ratio of total asset to total shareholders equity) to reflect the allocation efficiency of shareholders equity. Higher equity multiplier means a higher-level debt, i.e. higher asset-liability ratio. Given the pillar role of China's energy sectors in promoting industrial economy, broader state-owned attribute, and easier access to external credit, their equity multiplier may be positively associated with green production. Thus we hypothesize:

Hypothesis 2. The allocation of equity multiplier is positively associated with green production

### *2.2.3 The impact of tax structure allocation on green production.*

Different from internal financial resources allocation, firms also need to deal with challenges from external resources. Meanwhile, more policy tools are designed to inspire corporate initiatives in achieving greenization, e.g. taxation system and fiscal subsidy. One indicator describing corporate tax structure allocation is the ratio of tax paid to tax rebate, and how to set the broadly accepted schemes that dynamically adjust tax structure is often a challenge for governments. Accordingly, tax structure is also a kind of financial resources allocation dominated by governments while embodied in corporate capital flows. Our prior observations showed that environmental management of China's manufacturing firms is being improved. Further given that tax paid is a way to show corporate image, the less disparity between tax paid and tax rebate in China's energy sectors, and their elaboration on investing the rebated tax in green production, we infer that these sectors can bear the current gap between tax paid and tax rebate, and its structure may not be negatively associated with green production. Thus we hypothesize:

Hypothesis 3. The allocation of tax paid versus tax rebate is positively associated with green production.

## 2.3 How R&D input plays the moderating role?

Few studies directly bridged financial resources allocation, R&D input, and green production, while some indirect evidence regarding the gradient of green operations suggests that developing this bridge is advisable. Research in past two decades showed that higher market-oriented allocation (i.e. lower market distortion) enhanced corporate innovation efficiency, thus influencing the "input-output" efficiency in industrial sectors/regions. Recent literature further suggested establishing the link of resources allocation, innovation efficiency, and production efficiency. Inspired by prior studies that established transmission paths from resources allocation to outputs via multiple intermediate links, we expand these paths to green production fields. Existing conceptual frameworks inspire to analyze the impact of financial resources allocation on corporate greenization, while when it comes to the effectiveness of financial resources, R&D/innovation factors may help reconcile their possible negative impacts on environmental spheres. Prior studies found that market-oriented sectors have obtained less R&D subsidies in China, and the role of fiscal subsidy is crowded out by corporate internal R&D input. It shows that China's energy sectors that are largely dominated by state-owned shares with extensive pollutants emission need to invest more R&D resources based on both fiscal subsidy and their owned investment. Integrating our analysis on the relationship between financial resources allocation and green production as well as the increasing impact of R&D on corporate greenization, the possible moderation role of R&D input can be characterized as follows. Different levels of R&D input reflect corporate R&D preferences, and to address financial resources misallocation, firms can proactively adjust R&D input scale to reduce the possible negative impact of such misallocation on green production. As firms may encounter various levels of financial resources allocation, and insight from the resource-based view, R&D input that is closely relevant to economic outcome can be seen as a resource to help coordinate corporate overall greenization. Overall, the diverse governance structures of China's firms may trigger a significant disparity of R&D roles in environmental spheres, but prior studies less observed how R&D mitigates the possible conflicts between financial resources misallocation and green production, i.e. less linking resources (mis)allocation and environmental spheres. Given a broad state-owned attribute of China's energy sectors especially listed firms, inevitable monopoly/ oligopoly structures enhance the role of R&D in competitive edges. In this case, sustainable R&D inputs may help firms to address existing dilemmas. Based on above discussions about our key variables, we hypothesize:

Hypothesis 4. R&D input improves the impact of financial resources allocation on green production.

## 2.4 The theoretical model

We arrive at a model by drawing together essential components of theoretical development so far as Figure. 1. Guided by this conceptual framework, our empirical results will show how the allocation of different financial resources can evolve into green production via R&D input

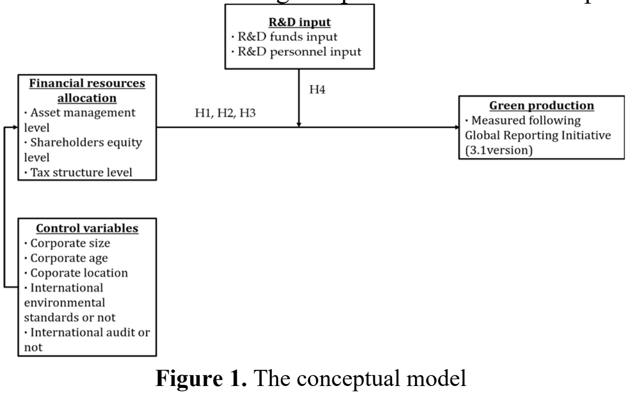

**Figure 1.** The conceptual model

## 3 Methodology

### 3.1 Data

We investigate China's listed energy firms whose basic profiles are acquired from Shanghai Stock Exchange and Shenzhen Stock Exchange, and 143 firms whose main business belong to energy sectors are observed. Given the availability and integrity of our data, we finally organize 254 firm-year observations spanned from 2010 to 2018.With respect to data source, following variables are surveyed from CSR reports: the level of green production, and whether firm publishing social responsibility information following the Sustainability Reporting Guideline compiled by Global Reporting Initiative (GRI3.1 version) or the Environment, Social, and Governance Index compiled by Stock Exchange of Hong Kong Exchange Ltd.(ESG). Further, following variables are surveyed from corporate annual reports: total staff, whether annual report audited by international certified accounting firms, asset allocation efficiency, shareholders equity allocation, tax structure allocation, R&D funds/personnel input. What's more, corporate listed age and headquarters' location are surveyed from http://www.eastmoney.com/ that is a professional financial website recording basic profiles and stock market quotation of China's firms.

### 3.2 Variables

Dependent variable: The level of green production is our dependent variable measured following the Global Reporting Initiative (GRI3.1 version). With respect to green production, GRI3.1 version designs environmental performance evaluation system that covers 30 indicators (17 core indicators and 13 additional indicators). Based on the introduction for each indicator by GRI3.1 version, it can be seen that EN1-EN2(Materials consumption), EN3-EN7(energy-saving), EN8-EN10 (water-saving), EN16-EN25(pollutant control), and EN26-EN27(cleaner products/services) involve features of green production. Thus we measure it following these 22 indicators. We use the Content Analysis Method to quantify the level of green production based on relevant information from CSR reports, i.e. surveying whether our samples well engage in above 22 indicators relevant to green production.

Independent variables: We arrange the ratio of asset impairment loss to total assets (%) as first independent variable to describe asset allocation efficiency, and the equity multiplier as second independent variable to describe shareholders equity allocation efficiency. Inspired by prior studies on CSR and the actual government incentive in China, we arrange the ratio of tax paid and tax rebate as third independent variable to describe tax structure allocation efficiency.

Moderating variables: We examine the moderating roles of both R&D funds input and R&D personnel input to show the robustness of their inputs. We measure R&D funds input by the ratio of R&D funds to operation revenue (%), and measure R&D personnel input by the ratio of R&D personnel to corporate total staff (%).

Control variables: We design following control variables that influence the level of independent, moderating, and dependent variables as well as their linkages based on prior studies, in order to consolidate our empirical results to truly show the role of antecedent variables of green production. (1) Corporate size(SIZE). We use the total number of staff to describe corporate size. (2) Corporate listed age(AGE). We define the age when one firm being listed as 1, the next year as 2, and on the analogy of this. (3) Corporate headquarter location(LOC). (4) Whether publishing green production information based on GRI3.1 version/ESG or not(GRI/ESG). These two guidelines both introduce how to collect data relevant to institutions' sustainability, and CSR reports that are compiled following GRI 3.1 version/ESG often show a clear logic structure with well-reported contents. Thus such reports may show top management's strong desires in corporate sustainability spheres. (5) Hiring international certified accounting firms to audit annual reports or not(IA). This hire does not completely indicate a high-quality annual report or impressive green production, while these accounting firms' global reputation may reduce the false of audited performance. Therefore, we survey whether following accounting firms were hired, i.e. Deloitte & Touche, Pricewaterhouse Coopers, Ernst & Young, and KMPG.

Table 1 shows the overview of all variables, including definitions and statistical data. Overall, Table 1 shows that China's energy sectors are experiencing a challenge in allocation efficiency of debt and tax structures, with a great disparity of R&D input structure as well.

**Table 1.** The overview of variables(N=254)

| Variables | Definitions | Min. | Max. | Mean | S.D. |
|---|---|---|---|---|---|
| GP | *Green production performance measured following GRI3.1 version* | 24.0 | 52.0 | 34.27 | 6.33 |
| SIZE | *Total staff, including all parent and subsidiary firms* | 173.0 | 476223.0 | 21410.07 | 37151.8 |
| AGE | *The time length of firm listing in Shanghai or Shenzhen Stock Exchange(year)* | 1.0 | 26.0 | 14.36 | 5.5 |
| LOC | *Eastern province/municipality(developed)=1; Non-eastern region(less-developed)=0* | 0.0 | 1.0 | 0.63 | 0.48 |
| GRI/ESG | *Organizing SO following GRI3.1 version/ESG=1; otherwise=0* | 0.0 | 1.0 | 0.47 | 0.5 |
| IA | *Hiring international certified accounting frim=1; otherwise=0* | 0.0 | 1.0 | 0.19 | 0.39 |
| AA | *The ratio of asset impairment loss to total assets(%)* | - 0.5 | 7.62 | 0.47 | 0.82 |
| SEA | *The equity multiplier* | 1.1 | 8.82 | 2.42 | 1.01 |
| TSA | *The ratio of tax paid and tax rebate* | - 23.05 | 13024.24 | 382.64 | 1334.12 |
| RDFI | *The ratio of R&D funds to operation revenue(%)* | 0.01 | 6.06 | 0.84 | 1.25 |
| RDPI | *The ratio of R&D personnel to total staff of firms(%)* | 0.11 | 52.46 | 10.19 | 9.29 |

Note: GP (green production); AA (asset allocation); SEA (shareholders equity allocation); TSA (tax structure allocation); RDFI (R&D funds input); RDPI (R&D personnel input), with the same as following Tables.

### 3.3 Data processing

Different measuring units of variables suggest standardizing raw data to make their distribution centralized, which can help reduce the negative interference of few outliers on empirical results. Further, we separately examine the moderating role of R&D funds and R&D personnel inputs to verify the robustness of R&D.

We firstly develop the robustness test for all variables to show what extent green production is robustly explained by antecedent variables. To achieve it, we use OLS estimation model, Fixed Effect model, and Random

Effect model to examine the causality in groups of both R&D input indicators as moderating variables, and we find that these testing methods show a similar causality trend. What's more, as general OLS estimation cannot well deal with the possible unobserved heterogeneity of panel data caused by time-and-individual disparity, we compare the applicability of Fixed Effect and Random Effect models. Through Hausman test, Random Effect model is more applicable to both R&D inputs indicators as Table 3 and Table 4. Therefore, we design following measuring models.

$$Y_{it} = \alpha + \beta_1 C_{it} + \beta_2 X_{it} + \beta_3 M_{1it} + \beta_4 X_{it} M_{1it} + \varepsilon_{it} \tag{1}$$

$$Y_{it} = \alpha + \beta_1 C_{it} + \beta_2 X_{it} + \beta_3 M_{2it} + \beta_4 X_{it} M_{2it} + \varepsilon_{it} \tag{2}$$

where $\mathrm{X_{it}}$ indicates independent variables. $\mathrm{M_{1it}}$ is R&D funds input, and $\mathrm{M_{2it}}$ is R&D personnel input. $\mathrm{C_{it}}$ indicates control variables. Further, $\alpha$ is the constant term, and $\varepsilon_{\mathrm{it}}$ is the random error term. i is the firm-level observation ( i =1…254), and t is the time-level observation (t=2010…2018). We decompose Equation (1) and Equation(2) into 4 testing steps and then examine the impact of $\mathrm{C_{it}}$, $\mathrm{C_{it} + X_{it}}$, $\mathrm{C_{it} + X_{it} + M_{it}}$, and $\mathrm{C_{it} + X_{it} + M_{it} + X_{it}M_{it}}$ on $\mathrm{Y_{it}}$, respectively.

## 4 Results

### 4.1 Correlation analysis

Table 2 shows that energy firms with more staff, more economically-developed geographical location, using GRI3.1/ESG, or hiring international certified accounting firms can better engage in green production. Further, firms' higher equity multiplier or higher ratio of tax paid to tax rebate also better engage in green production. While both R&D funds input and R&D personnel input are negatively associated with green production, which preliminarily indicates that the rise of green production performance does not strongly rely on R&D input at present. What's more, there is a significant correlation between R&D input indicators, while their correlation coefficient is not very high (0.104), which indicates that different R&D input indicators may not harmoniously alter in China's energy sectors. On one hand, many R&D indicators may influence corporate whole operations in a variety of ways. On the other hand, it inspires to examine whether different R&D profiles can always play robust roles in the targeted performance. Following, we examine variables' causality to verify our hypotheses.

**Table 2.** Correlation coefficients (Spearman coefficients, N=254)

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GP | | | | | | | | | | | | | | | | | |
| STAFF | 0.56*** | | | | | | | | | | | | | | | | |
| AGE | -0.12* | -0.32*** | | | | | | | | | | | | | | | |
| LOC | 0.26*** | 0.05 | -0.05 | | | | | | | | | | | | | | |
| GRI/ESG | 0.39*** | 0.33*** | -0.04 | 0.16** | | | | | | | | | | | | | |
| IA | 0.17*** | 0.26*** | 0.02 | 0.37*** | 0.23*** | | | | | | | | | | | | |
| AA | 0.07 | 0.11* | 0.26*** | 0.07 | 0.04 | 0.17*** | | | | | | | | | | | |
| SEA | 0.24*** | 0.30*** | -0.17*** | -0.15** | 0.25*** | -0.08 | -0.03 | | | | | | | | | | |
| TSA | 0.29*** | 0.23*** | 0.11* | -0.07 | 0.15** | 0.23*** | 0.11* | 0.05 | | | | | | | | | |
| RDFI | -0.10* | 0.17*** | -0.30*** | -0.06 | -0.17*** | -0.07 | 0.03 | -0.24*** | -0.07 | | | | | | | | |
| RDPI | -0.13** | -0.15** | -0.03 | 0.22*** | 0.06 | 0.24*** | -0.01 | -0.08 | -0.1 | 0.10* | | | | | | | |
| AA× RDFI | -0.03 | 0.19*** | -0.01 | 0.01 | -0.07 | 0.08 | 0.73** | -0.19*** | 0 | 0.63*** | 0.05 | | | | | | |
| SEA× RDFI | -0.05 | 0.23*** | -0.35*** | -0.08 | -0.12* | -0.1 | 0.03 | -0.03 | -0.07 | 0.97*** | 0.11* | 0.62*** | | | | | |
| TSA× RDFI | 0.15** | 0.27*** | -0.07 | -0.08 | 0.01 | 0.14** | 0.11* | -0.15** | 0.75*** | 0.57*** | -0.01 | 0.41*** | 0.54*** | | | | |
| AA× RDPI | 0.07 | 0.11* | 0.17*** | 0.17*** | 0.1 | 0.27*** | 0.86*** | -0.21 | 0.06 | 0.1 | 0.42*** | 0.69*** | 0.11* | 0.11* | | | |
| SEA× RDPI | -0.05 | -0.03 | -0.08 | 0.11* | 0.15** | 0.14** | -0.01 | 0.31*** | -0.09 | 0 | 0.89*** | -0.01 | 0.09 | -0.08 | 0.39*** | | |
| TSA× RDPI | 0.27*** | 0.20*** | 0.06 | 0.04 | 0.16*** | 0.31*** | 0.09 | 0.03 | 0.90*** | 0.01 | 0.29*** | 0.04 | 0.01 | 0.73*** | 0.23*** | 0.27*** | |

Note: *p≤0.10(Two-tailed), **p≤0.05(Two-tailed), ***p≤0.01(Two-tailed), with the same as following Tables.

### 4.2 Empirical results

Table 3 and Table 4 show the impact of financial resources allocation on green production with moderating roles of R&D funds input and R&D personnel input, respectively. Values of R2 in both Tables show that with the addition of variables in econometric models, the change of green production is better explained.

Since it is usually assumed that the disturbance terms of different observed group are mutually independent in the panel data, we further estimate the cluster robust standard errors of each variable at the year-level to show the spatial correlations of error terms. Table 3 and Table 4 both show the small cluster robust standard errors, i.e. a centralized data distribution. Further, we organize some empirical tests to verify our data quality. First, D.W. test is developed to show the serial correlation of variables with a finding that all D.W. values are around 2, which indicates that the residual of variables obeys a normal distribution. Second, Chi-square test is also developed to measure deviation degrees between actual observation and theoretical inference of our data, and asymptotic significance shows that it has almost no deviation between variables' observed and theoretical values, i.e. unbiased prediction for variables' function. Third, Hausman test is developed to verify the existence of endogeneity in our data with a finding that the value of Prob>chi2 of each model approaches 0, which shows a non-endogeneity of variables. These pre-tests intensify our data's quality and robustness of causality among variables.

**Table 3.** Empirical results with R&D funds input's moderating role (N=254)

| Variables | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| Constant | -2.71e-09***(0.022) | -3.40e-09***(0.023) | -2.80e-09***(0.021) | -2.90e-09***(0.024) |
| SIZE | 0.392***(0.146) | 0.377***(0.133) | 0.380***(0.138) | 0.378***(0.139) |
| AGE | -0.005(0.039) | -0.003(.036) | -0.036(0.030) | -0.021(0.032) |
| LOC | 0.238***(0.027) | 0.279***(0.032) | 0.282***(0.032) | 0.295***(0.032) |
| GRI/ESG | 0.297***(0.023) | 0.280***(0.029) | 0.276***(0.029) | 0.278***(0.027) |
| IA | -0.119**(0.018) | -0.113**(0.022) | -0.132**(0.021) | -0.135**(0.020) |
| AA | | 0.019(0.030) | 0.030(0.027) | 0.093(0.044) |
| SEA | | 0.106**(0.065) | 0.075**(0.065) | 0.079(0.061) |
| TSA | | 0.153***(0.027) | 0.150***(0.031) | 0.052(0.047) |
| RDFI | | | -.0123**(0.046) | -0.029(0.079) |
| AA×RDFI | | | | -0.127(0.067) |
| SEA×RDFI | | | | -0.054(0.092) |
| TSA×RDFI | | | | 0.139*(0.066) |
| Year(Firm) | Controlled | Controlled | Controlled | Controlled |
| $R^2$ | 0.343 | 0.378 | 0.387 | 0.403 |
| *Wald chi*$^2$ | 129.20*** | 146.16*** | 153.90*** | 162.51*** |
| *D.W.* | 1.866 | 1.841 | 1.862 | 1.902 |

Note: Robust standard errors in parentheses are cluster standard errors at the year-level with the same as Table 4.

**Table 4.** Empirical results with R&D personnel input's moderating role (N=254)

| Variables | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| Constant | -2.71e-09***(0.022) | -3.40e-09***(0.023) | -4.05e-09***(0.029) | -4.01e-09***(0.029) |
| SIZE | 0.392***(0.146) | 0.377***(0.133) | 0.359***(0.127) | 0.360***(0.128) |
| AGE | -0.005(0.039) | -0.003(.036) | -0.009(0.040) | -0.012(0.036) |
| LOC | 0.238***(0.027) | 0.279***(0.032) | 0.295***(0.033) | 0.296***(0.035) |
| GRI/ESG | 0.297***(0.023) | 0.280***(0.029) | 0.273***(0.029) | 0.272***(0.030) |
| IA | -0.119**(0.018) | -0.113**(0.022) | -0.088**(0.014) | -0.086***(0.030) |
| AA | | 0.019(0.030) | 0.012(0.031) | 0.055(0.071) |
| SEA | | 0.106**(0.065) | 0.104*(0.065) | 0.111(0.120) |
| TSA | | 0.153***(0.027) | 0.153***(0.031) | 0.158**(0.040) |
| RDPI | | | -0.108**(0.036) | -0.072(0.183) |
| AA×RDPI | | | | -0.053(0.088) |
| SEA×RDPI | | | | -0.017(0.191) |
| TSA×RDPI | | | | -0.007(0.032) |
| Year(Firm) | Controlled | Controlled | Controlled | Controlled |
| $R^2$ | 0.343 | 0.378 | 0.384 | 0.385 |
| *Wald chi*$^2$ | 129.20*** | 146.16*** | 152.17*** | 150.77*** |
| *D.W.* | 1.866 | 1.841 | 1.86 | 1.858 |

Empirical results show that SIZE, LOC, and GRI/ESG can significantly improve green production no matter whether considering the involvement of other variables with their marginal effects within 37.66%~39.23%, 23.84%~29.52%, and 27.60%~29.70%, respectively. Their marginal coefficients indicate that corporate size, geographical location, and the acceptability of international sustainable development standards can strongly lead green production of China's energy sectors. While hiring international certified accounting firms has not inspired these sectors to better focus on greenization, which is different from the influence trend of correlation analysis and our prior observations that for the whole manufacturing sectors, internationalized audit can help improve their sustainability. Further, the marginal coefficients of AGE show that young firms are focusing more on green production while with no statistical significance. What's more, the role of LOC indicates a positive relationship between region economy and corporate sustainability in China.

All of current financial resources allocation status has positive impacts on green production, while marginal coefficients of SEA and TSA are statistically significant as Model 2, which verifies Hypothesis 2 and Hypothesis 3. Considering the feature of China's economy status and energy sectors, these results reveal that higher equity multiplier (i.e. higher asset-liability ratio) can help energy firms organize more funds in the broader spheres, and it also implies that such external debt as a kind of available resource can play an inspiring role in corporate sustainability, especially helping addressing problems out of business operations. Therefore, to China's energy sectors that have a large business scale and need to take on more environmental governance tasks compared with other sectors, external funds from diverse financing channels can help mitigate internal financial pressure and thus make it possible for more sustainable cash flows. Further, the positive impact of the ratio of tax paid to tax rebate suggests that current tax structure has not seriously discourage the enthusiasm of China's energy sectors to pursue sustainability.

With respect to the role of R&D, although there exists a lower correlation coefficient between these two R&D input indicators, results in Table 3 and Table 4 suggest the robust role of different kinds of R&D inputs. On the one hand, both R&D funds input and R&D personnel input do not inspire green production. It may be because of the lower scale of R&D inputs. For energy sectors, they need the cumulative R&D capability to deal with their reliance on traditional energies and future energy price rise. In this regard, both R&D input indicators are at a low level as Table 1. Accordingly, the current R&D input scale may be hard to provide solid backings for greenization of China's energy sectors.

On the other hand, Model 4 of Table3 and Table 4 describes following pictures regarding the moderating role of R&D input. First, both R&D input indicators can help mitigate the allocation pressure of asset, shareholders equity, and tax structure. Specifically, compared with marginal coefficients of financial resources allocation in Model 2, the involvement of R&D input indicators make these coefficients turn from positive to negative as a whole as Model 4. R&D input allows China's energy sectors China's energy sectors to reduce asset impairment loss and external debt, and it also suggests government to narrow the gap between tax paid and tax rebate. Overall, the involvement of R&D input gives a broader space for China's energy sectors in adjusting previous financial resources allocation. What's more, R&D input enhances financial resources' anti- risk capability, and relevant policy implications in terms of tax relief are also in line with the advocacy of China's government that encourages heavy-polluting sectors to march towards the advanced manufacturing. Overall, these two R&D input indicators both help release the allocation pressure of all three financial resources, and thus provide a more flexible way to deal with financial crisis.

The comparative analysis between these two R&D input indicators consolidates the robustness of different R&D behaviors in harmonizing finance and sustainability spheres in China's heavy-polluting sectors, with the following key findings. First, the current R&D input structure is not very reasonable, and relevant indicators do not have a positive impact on green production. Second, different R&D input modes may play a similar role in China's energy sectors, which indicates that these sectors establish an overall planning for R&D activities. Accordingly, their R&D activities may be concurrently improved. Our robustness analysis indicates the prominent role of R&D input in improving the relationship between financial resources allocation and green production, and the role different kinds of financial resources can be improved. Therefore, Hypothesis 4 is verified.

## 5. Conclusion

This paper clarifies the impact of financial resources allocation on green production in the moderating role of R&D input in China's energy sectors. We find that corporate R&D input is still at a low level, and it has not improved green production. While R&D input helps release the allocation pressure of financial resources in green production, and such moderating roles show a robustness in different kinds of R&D inputs. Our findings suggest exploring more systematic transmission paths between production factors allocation and corporate greenization to deal with possible less-efficient allocations as a cask effect of corporate greenization, especially in heavy-polluting sectors that need to take initiative for environmental management.

## Acknowledgements

We thank funding supports from Humanities and Social Science Project of the Ministry of Education of China (Grant No. 20YJC790082), Chinese Postdoctoral Science Foundation (Grant No. 2020M681537), Philosophy and Social Science Research Planning Project of Heilongjiang Province (Grant No. 19JLC117), Fundamental Research Funds for Central Universities (Grant No. 3072020CFW0908 and Grant No. 3072020CFW0903), National Social Science Fund of China (Grant No. 17BGL204), and Philosophy and Social Science Research Planning Project of Hangzhou (Grant No. Z21JC094).

## References

1. Porter ME, van der Linde C. Green and competitive: Ending the stalemate. Harv Bus Rev 1995;73(5):120-134.
2. Wong CWY, Lai KH, Shang KC, Lu CS, Leung TKP. Green operations and the moderating role of environmental management capability of suppliers on manufacturing firm performance. Int J Prod Econ 2012;140:283-294.
3. Rahman MS, Noman AH, Shahari F, Aslam M, Gee CS, Ruhanalsa C, Pervin S. Efficient energy consumption in industrial sectors and its effect on environment: A comparative analysis between G8 and Southeast Asian emerging economies. Energy 2016;97:82-89.
4. Shi J, Li H, Guan J, Sun X, Guan Q, Liu X. Evolutionary features of global embodied energy flow between sectors: A complex network approach. Energy 2017;140:395-405.
5. Huang YH, Wu JH. Analyzing the driving forces behind CO2 emissions and reduction strategies for energy-intensive sectors in Taiwan, 1996-2006. Energy 2013;57:402-411.
6. Olonscheck M, Walther C, Lüdeke M, Kropp JP. Feasibility of energy reduction targets under climate change: The case of the residential heating energy sector of the Netherlands. Energy 2015;90:560-569.
7. Shen P, Yang B. Projecting Texas energy use for residential sector under future climate and urbanization scenarios: A bottom-up method based on twenty-year regional energy use data. Energy 2020;193:116694.
8. Bartelsman E, Haltiwanger J, Scarpetta S. Cross-country differences in productivity: The role of allocation and selection. Am Econ Rev 2013;103(1):305-334.
9. Yang M, Yang F, Sun C. Factor market distortion correction, resource reallocation and potential productivity gains: An empirical study on China's heavy industry sector. Energ Econ 2018,69:270-279.
10. Jin W, Zhang H, Liu S, Zhang, H. Technological innovation, environmental regulation, and green total factor efficiency of industrial water resources. J Clean Prod 2019,211:61-69.
11. Liu Y, Zhu Q, Seuring S. Linking capabilities to green operations strategies: The moderating role of corporate environmental proactivity. Int J Prod Econ 2017;187:182-195.
12. Liu Y, Zhang Y, Batista L, Rong K. Green operations: What's the role of supply chain flexibility?. Int J Prod Econ 2019;214:30-43.
13. Geels FW. The impact of the financial-economic crisis on sustainability transitions: Financial investment, governance and public discourse. Environ Innov Soc Tr 2013;6:67-95.
14. Brem A, Nylund P, Viardot E. The impact of the 2008 financial crisis on innovation: A dominant design perspective. J Bus Res 2020;110:360-369.
15. Ryzhenkov M. Resource misallocation and manufacturing productivity: The case of Ukraine. J Comp Econ 2016;44:41-55.
16. Shenoy A. Market failures and misallocation. J Dev Econ 2017;128:65-80.
17. Bento P, Restuccia D. On average establishment size across sectors and countries. J Monetary Econ 2020;In press.
18. Chung Y, Fare R, Grosskopf S. Productivity and undesirable outputs: A directional distance function approach. J Environ Manage 1997;51(3):229-240.
19. Fair R, Grosskopf S, Pasurka CA. Accounting for air pollution emissions in measures of state manufacturing productivity growth. J Regional Sci 2001;41(3):381-409.

20. Tombe T, Winter J. Environmental policy and misallocation: The productivity effect of intensity standards. J Environ Econ Manage 2015;72:137-163.
21. Bian Y, Song K, Bai J. Market segmentation, resource misallocation and environmental pollution. J Clean Prod 2019;228:376-387.
22. Chen PH, Ong CF, Hsu SC. The linkages between internationalization and environmental strategies of multinational construction firms. J Clean Prod 2016;116:207-216.
23. Hötte K. How to accelerate green technology diffusion? Directed technological change in the presence of coevolving absorptive capacity. Energ Econ 2020;85:104565.
24. Murphy KM, Shleifer A, Vishny RW. Income distribution, market size, and industrialization. Q J Econ 1989;104:537-564.
25. Restuccia D, Rogerson R. Policy distortions and aggregate productivity with heterogeneous establishments. Rev Econ Dynam 2008;11(4):707-720.
26. Hsieh CT, Klenow PJ. Misallocation and manufacturing TFP in China and India. Q J Econ 2009;124(4):1403-1448.
27. Aoki S. A simple accounting framework for the effect of resource misallocation on aggregate productivity. J Jpn Econ 2012;26 (4):473-494.
28. Banerjee AV, Moll B. Why does misallocation persist?. Am Econ J Macroecon 2010;2(1):189-206.
29. Buera FJ, Shin Y. Productivity growth and capital flows: The dynamics of reforms. Am Econ J Macroecon 2017;9(3):147-185.
30. Scarpellini S, Marín-Vinuesa LK, Portillo-Tarragona P, Moneva JM. Defining and measuring different dimensions of financial resources for business eco-innovation and the influence of the firms' capabilities. J Clean Prod 2018;204:258-269.
31. Hasan MM, Habib A. Corporate life cycle, organizational financial resources and corporate social responsibility. J Contemp Account Econ 2017;13:20-36.
32. Holz CA. The impact of the liability-asset ratio on profitability in China’s industrial state-owned enterprises. China Econ Rev 2002;13:1-26.
33. Alexopoulos I, Kounetas K, Tzelepis D. Environmental and financial performance. Is there a win-win or a win-loss situation? Evidence from the Greek manufacturing. J Clean Prod 2018;197:1275-1283.
34. Kleindorfer PR, Singhal K, Van Wassenhove LN. Sustainable operations management. Prod. Oper. Manage. 2005;14(4):482-492.
35. Hitt MA, Xu K, Carnes CM. Resource based theory in operations management research. J Oper Manag 2016;41:77- 94.
36. Bernardo MR, Campani CH. Liability driven investment with alternative assets: Evidence from Brazil. Emerg Mark Rev 2019; 41:100653.
37. Liang D, Liu T. Does environmental management capability of Chinese industrial firms improve the contribution of corporate environmental performance to economic performance? Evidence from 2010 to 2015. J Clean Prod 2017;142: 2985-2998.
38. Liu T, Zhang Y, Liang D. Can ownership structure improve environmental performance in Chinese manufacturing firms? The moderating effect of financial performance. J Clean Prod 2019;225:58-71.
39. Furman JL, Porter ME, Stern S, The determinants of national innovative capacity. Res Policy 2002;31(6):899-933.
40. Porter ME, Stern S. National innovation capacity in world economic forum 2002: The Global Competiveness Report 2001-2002. New York: Oxford University Press 2002.
41. Liu Z, Li X. Has China’s Belt and Road Initiative promoted its green total factor productivity?—Evidence from primary provinces along the route. Energ Policy 2019;129:360-369.
42. Yuan B. Effectiveness-based innovation or efficiency-based innovation? Trade-off and antecedents under the goal of ecological total-factor energy efficiency in China. Environ Sci Pollut R 2019;26(17):17333-17350.
43. Yuan B, Xiang Q. Environmental regulation, industrial innovation and green development of Chinese manufacturing: Based on an extended CDM model. J Clean Prod 2018,176:895-908.
44. Boeing P. The allocation and effectiveness of China’s R&D subsidies-Evidencefrom listed firms. Res Policy 2016;45:1774-1789.
45. Alazzani A, Wan-Hussin WN. Global reporting initiative’s environmental reporting: A study of oil and gas companies. Ecol Indic 2013;32:19-24.
46. Chen J, Tang O, Feldmann A. Applying GRI reports for the investigation of environmental management practices and company performance in Sweden, China and India. J Clean Prod 2015;98:36-46.
47. Vigneau L, Humphreys M, Moon J. How do firms comply with international sustainability standards? Processes and consequences of adopting the Global Reporting Initiative. J. Bus. Ethics 2015;131(2):469-486.
48. Yu W, Ramanathan, R. An empirical examination of stakeholder pressures, green operations practices and environmental performance. Int J Prod Res 2015;53(21):6390-6407.
49. Amran A, Lee SP, Devi SS. The influence of governance structure and strategic corporate social responsibility toward sustainability reporting quality. Bus Strat Environ 2014;23(4):217-235.
50. Gao C, Sun M, Shen B, Li R, Tian L. Optimization of China's energy structure based on portfolio theory. Energy 2014;77:890-897.

51. Kong D, Yang X, Xu J. Energy price and cost induced innovation: Evidence from China. Energy 2020;192:116586.