Green Finance and Green Innovation of Heavily-polluting Industries: Evidence from Chinese Listed Companies

Yalin Jiang, Fengying Wang, Chong Guo, and Yingyu Wu

***Abstract*—While supporting the development of green industries, the upgrading and transformation of heavily-polluting (HP) industries are of great significance to the achievement of the dual objectives of economic advancement and environmental protection in China. Green innovation (GI) is a crucial measure to address the development threats faced by HP industries. This paper studies the impact of green finance (GF) on the HP firms' GI, the results show a positive association between GF and HP firms' GI, indicating that GF can stimulate HP firms to improve their GI. Additionally, the positive effect of GF on GI is heterogeneous depending on property rights and corporate regions, state-owned enterprises, and companies located in central and eastern regions have a higher level of green innovation. Our findings provide important policy implications for promoting HP firms' green development.**

***Index Terms*—Heavily-polluting industries, green finance, green innovation, China.**

I. Introduction

China's economy is at a critical stage of shifting from fast growth to high-quality development, meaning that the economic growth would rely more on technological upgrading and GI rather than resource consumption. HP companies have made great contributions to China's economic growth, but their excessive energy consumption and high pollutant emissions have become a primary cause of ecological impairment and atmospheric pollution. Therefore, pollution abatement of HP firms is imperative to the achievement of high-quality economic development.

GI, which aims to reduce pollution by developing new production processes, methods, products, and services [1], plays a significant role in HP firms' green development. However, although the significance of GI is proliferating, GI cannot well-developed by solely relying on companies due to its characteristic of "dual externality". In addition to the positive externality of knowledge spillover of all kinds of innovations, GI also benefits the society by improving energy efficiency, reducing carbon emissions and promoting resource conservation. Therefore, the provision of policy incentives and financial support is crucial to promote the advancement of GI [2].

Green finance (GF), which is an innovative financial product and includes green credit, green securities, green investment, and carbon finance, can provide support for the development of HP firms' GI. Research dedicated to GF mainly focuses on its implementation effectiveness [3], its impact on economic development [4], and environmental protection [5]. Although GI is vital to reducing HP firms' pollution, relatively little research link GF with GI of HP companies.

Theoretically, the relation between GF and HP firms' GI is ambiguous. On the one hand, GF may hinder HP firms to employ GI practices due to financing constraint imposed by GF. GF has the dual attributes of "green" and "finance", leading to an uncertain and complex impact on HP firms' GI. The "finance" attribute has resource distribution and supervision functions. The resource distribution function means that the financial system can guide financial resources flow to industries with high utilization of financial resources instead of inefficient industries, realizing the maximum utilization of resources [6]. Compared with non-HP firms, funds allocated to HP firms are more likely to result in low levels of resource usage due to their high environmental risk, which may reduce the funds flowed to HP firms. Furthermore, as "economic man", financial institution's objective is interest maximation. The attribute of "green" requires the funds acquired to be employed to implement environmental initiatives, however, if HP firms obtained the GF, this means the supervision cost can be relatively high due to their characteristics of operation activities. Lastly, GI investment has characteristics of high up-front investment requirements, long payback period, and strong uncertainty of return. This may make HP firms difficult to obtain GF funds, which can result in HP firms' severe financing constraint, leading to insufficient GI investment.

On the other hand, GF may have a positive impact on HP firms' GI development. First, GF may create strong incentives for HP firms to embed GI into their company strategies, which is one of the crucial success factors of GI [4], because the acquired GI can positively impact corporate environmental performance by reducing the consumption of dangerous materials, energy usage, and air emissions [7], enabling HP firms to get access to GF. Second, theoretically, based on the signalling theory, GF conveys a positive signal about firms' operation. Information asymmetry is one of the important reasons for the low GI of HP enterprises.

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Compared with other creditors, financial institutions have information advantages and can gain firms' comprehensive and private information [6]. Therefore, GF issuance conveys an important positive signal to external investors. This may increase HP firms' motivation to invest in GI, exerting a positive impact on their GI.

Therefore, this study attempts to answer the following questions: Facing with tremendous environmental pressure, would GF drive HP firms to improve their GI? Second, if GF can stimulate HP firm' GI, does this effect vary based on property ownership and corporate locations? To answer the above questions, we use the data on 588 HP listed companies from 2010 to 2017 as a sample to explore the correlation between GF and HP firms' GI.

This study makes several contributions. First, a host of scholars investigated the determinants of GI from a micro perspective, including political capital [8] and institutional pressure [9], researchers seldom pay attention to the macro-level factors, we fill this gap by examining whether GF can drive HP firms' GI improvement. Second, prior research considers the role of GF in promoting GI of environmentally friendly firms rather than HP companies, which is of great importance because HP firms' green development is crucial for the overall economic high-quality development. Third, our finding that GF exerts a strong and significant incentive effect on HP firms' GI can provide a valuable reference for policymakers to promote HP firms' green development.

II. Data and Methodology

We use HP companies[1] listed on the Shenzhen Stock Exchange (SZSE) and the Shanghai Stock Exchange (SSE) from 2010 to 2017 as a sample. Two primary variables for our study are corporate GI and GF, we use the logarithm of the authorization of green patent count as the indicator of GI[2] [10]; The GF development index for provinces and municipalities in China, which is constructed by employing the GPCA method that combines PCA and time series analysis, is obtained from [11]. Other financial data is acquired from the CSMAR databases. All the variables are summarized in Table I:

The following equation is used to test the influence of GF on HP firms' GI:

$$GI_{it} = \_cons_{it} + \alpha_1 \times GF_{it} + \alpha_j \times CVs + \Sigma Year + \Sigma Industry + \varepsilon_{it} \quad (1)$$

[1] According to the "Environmental Inspection of Listed Companies" issued by Ministry of Ecology and Environment of the People's Republic of China, the 15 HP industries segments are: thermal power, iron and steel, cement, electrolytic aluminum, metallurgy, chemical, petrochemical, building materials, paper, brewing, pharmaceutical, fermentation, textiles, leather and mining.

[2] The data on green patents is obtained from State Intellectual Property Office of China (SIPOC). Based on "IPC green invention" issued by the World Intellectual Property Organization (WIPO), we retrieved and matched the number of environmental patent applications filed by each HP company from samples in the database of the SIPOC. We searched green patents for authorization and applied its logarithm to measure GI, we also used the other three types of green patents (authorization of green utility patent, authorization of green invention patent and application for total green patents) for robustness tests.

In equation (1), the dependent variable GI_{it} represents the level of GI of the HP company *i* in year *t*, and the primary explanatory variable GF_{it} represents the regional GF development level (province, municipality, and autonomous region) where the HP company *i* is located in year *t*. CVs denotes control variables. Variable definitions are shown in Appendix A. The coefficient (α_1) of GF_{it} is our main interest. If α_1 is significantly positive, it indicates GF can effectively drive HP firms to improve their GI.

III. Empirical Results

Table I shows the empirical description of the variables in Equation (1). The average corporate GI is valued at 0.248, indicating a relatively low level of GI.

TABLE I: Descriptive Statistics of Main Variables

Variable	mean	p50	Std.	min	max	N
GI	0.248	0.000	0.607	0.000	3.219	3521
GF	0.454	0.167	0.917	-0.683	3.346	3521
Size	22.376	22.136	1.374c	19.874	26.054	3521
Lev	0.447	0.455	0.198	0.052	0.859	3521
ROA	0.059	0.052	0.049	-0.137	0.235	3521
Age	1.989	2.197	0.869	0.000	3.178	3521
Age2	4.709	4.828	2.935	0.000	10.100	3521
Ins	0.350	0.350	0.242	0.000	0.864	3521
EPS	0.355	0.254	0.465	-0.900	2.494	3521

This table reports the descriptive statistics of the main variables in our study. Specifically, this table presents pooled means, 50% quantiles, standard deviation, minimum value, and maximum value, and the number of observations of dependent variables, the independent variable of interest, and control variables. The sample consists of 3,521 firm-year observations from 2007 to 2018, representing 588 individual firms. All continuous variables are winsorized at 1% and 99% percentiles. Refer to Appendix 1 for variable definitions.

TABLE II: Green Innovation and Green Finance: Baseline Results

Variable	(1)	(2)
GF	0.0547***	0.0410***
	(0.0137)	(0.0125)
Size		0.1356***
		(0.0122)
Lev		-0.2932***
		(0.0606)
ROA		-1.0456***
		(0.2924)
Age		0.0717**
		(0.0363)
Age^2		-0.0335***
		(0.0108)
Ins		0.2828***
		(0.0434)
EPS		0.0991**
		(0.0403)
_cons	0.4910***	-2.6995***
	(0.0760)	(0.2645)
N	3521	3521
R^2	0.150	0.226

Note: t-statistics are presented in parentheses and are calculated on the basis of standard errors clustered at the firm level. *** ,** , and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table II reports the main regression results of Equation (1), Column (1) and (2) shows the estimation results of equation (1) without control variables and with control variables, respectively. The coefficient on GF is significantly positive (coefficient =0.0547, β=1% without control variables; coefficient=0.0410, β=1% with control variables), suggesting that GF has a significantly positive impact on HP companies' GI.

One of the possible explanations is that GF is effective in stimulating HP firms to improve their GI. GF, which provides preferential and low-interest finance sources for companies, enabling firms to continuously invest in green behaviours, which can increase firms' legitimacy status, social reputation, and corporate image. These benefits can motivate firms to improve their GI because they cannot only increase HP firms' sales revenue but also offset the GI-related expenditure; second, the obtaining of GF conveys a positive signal of HP firms' recognized status by financial institutions, increasing their impetus to improve their GI.

IV. Robustness Test and Heterogeneity Analysis

The above results withstand various robustness checks, in unstipulated results (see Appendix B), the following tests are carried out: (1) new measurement of GI: replacing dependable variable with the following four substitute variables including authorization of green invention patents, the authorization of green utility patents, the application of green patents and whether firms have obtained ISO 14001[3], the findings support the baseline regression results; (2) lag treatment of GF: the independent variable of GF is lagged 1 year to reduce concerns with reserve causality; (3) Year×industry fixed effect: the year×industry fixed effect is introduced to better mitigate the issue of omitted variables bias. The results remain qualitatively the same. (4) using of difference-in-difference (DID) model (see Appendix C): given that green credit is an important element of GF, we use the promulgation of "Green Credit Guidelines (GCG)" as a quasi-natural experiment to further mitigate the issue of endogeneity (see Appendix C). The results of the DID model show that GI of HP enterprises was significantly increased after the enaction of the GCG policy, indicating that the GCG policy is effective in stimulating HP firms to improve their GI, which is consistent with the baseline regression results.

Moreover, the heterogeneity analysis was conducted by clustering the sample based on property rights and geographic locations to further examine the impact of GF on HP firms' GI (see Appendix D). The estimated results indicate the following results: (1) Compared with state-owned enterprises (SOEs), GF exerts a more positive impact on NSOEs' GI because NSOEs are likely to undertake more responsibilities of environmental protection due to their close connections with the government. (2) Compared with HP companies in western regions, GF imposes a more positive impact on the GI of HP companies in eastern and central regions. This is probably because the level of economic and financial development in the central and eastern regions is much higher than that in the western regions, so the signal transmitted by GF can be easier to be received and understood by stakeholders, consequently, HP firms in eastern and central regions have stronger incentive to improve their GI.

[3] GI can be divided into green technology innovation and green management innovation [12]. ISO 14001 is a standard which provides an environmental management framework to embed environmental management practices into a firm's operations. It has been steadily and increasingly adopted and achieved high levels of popularity in the world as the most recognized environmental management program. Thus, green management innovation (whether HP firms have obtained the ISO 14001 certification) is used to measure corporate GI.

V. Conclusion

Using firm-level GI data combined with provincial GF data in China from 2007 to 2018, this study aims to empirically explore the impact of GF on GI of HP firms. We found that GF has a significant positive impact on promoting HP firms' GI. Our findings are conducive to improve HP firms' environmental performance, thereby realizing the coordinated and green development of the economy.

This study offers several theoretical and practical implications. First, our findings contribute to GF in the finance literature and GI in CSR literature. Findings derived from our research fill the research gap by focusing on the association between GF and HP firms' GI. Second, our study provides some insights into the improvement of HP firms' GI, facilitating the transformation of HP industries and sustainable economic development.

Appendix

To further confirm the above results, we use the promulgation of the "Green Credit Guidelines (GCG)" policy as a quasi-natural experiment. This policy, which requires China banks restrict the amount of loans given to firms and projects with poor environmental performance and direct funds flowed to environmentally friendly enterprises, was initiated on February 24, 2012 in China. It indicates that the banking sector needs to implement GCG policy from a strategic and operational level. Given that green credit is an important element of GF, we use GCG policy to testify whether it increases HP firms' motivation to improve GI.

$$GTI_{it} = \_cons_{it} + \beta_1 \times DID_{it} + \beta_j \times CVs + \Sigma Year + \Sigma Firm + \tau_{it} \quad (1)$$

In equation (1), variable DID is acquired by $Treat_i \times After_t$, among these, $Treat_i$ represents the group dummy variable, while companies in the experimental group is set to 1, firms in control group is set to 0； After t denotes the event dummy variable, which is set to 1 after 2012 and set to 0 before 2012. ∑Year and ∑Firm represents the year fixed effect and industry fixed effect, respectively. CVs stands for control variables, which are consistent with the CVs of the baseline regression. We focus on the coefficient of DID in Appendix C, which is 0.0422 at 1% significance level. The empirical results suggest that GI of HP enterprises was significantly increased after the promulgation of the GCGs, indicating that the GCG policy is effective in stimulating HP firms to improve their GI, which is consistent with the baseline regression results.

APPENDIX A: VARIABLE DEFINITIONS

	Variable	Abbreviation	Description
Dependent variable	Green Innovation	GI	Natural logarithm of number of authorizations of GI patents counts
Independent variable	Green Finance	GF	Green finance development index for provinces and municipalities measured by Zhang *et al*. (2020)
Control variable	Firm Size	Size	Natural logarithm of total assets
	Leverage	Lev	Total assets/total liabilities
	Return on Assets	ROA	Net profit/total assets
	Firm Age	Age	The logarithm of the number of years since the firm was listed
	Firm Age^2	Age^2	The square of the age of the enterprise
	Institutional investors' shareholding	Ins	The proportion of institutional shareholding
	Earnings per share	EPS	After-tax profit / the total equity

APPENDIX B: ROBUSTNESS TESTING I: NEW MEASUREMENT OF GI, LAG TREATMENT OF GF AND THE INTRODUCTION OF YEAR ×INDUSTRY FIXED EFFECT

Variable	(1) New measurement of GI: No. of the authorization of green invention patents	(2) New measurement of GI: No. of the authorization of green utility patents	(3) New measurement of GI: No. of the application of total GI patents	(4) New measurement of GI: Whether firms have obtained ISO 14001 certification	(5) Lagged 1-year independent variable	(6) Introduction of year ×industry fixed effect
GF	0.0302***	0.0294***	0.0642***	0.0439***		0.0428***
	(0.0090)	(0.0098)	(0.0156)	(0.0163)		(0.0127)
L. GF					0.0424***	
					(0.0152)	
CVs	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
Year	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
Industry	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
Year × Industry	*NO*	*NO*	*NO*	*NO*	*NO*	*YES*
_cons	-1.4277***	-2.1719***	-3.4521***	0.1742	-2.6852***	-2.8624***
	(0.1753)	(0.2288)	(0.3045)	(0.3005)	(0.3047)	(0.2964)
N	3521	3521	3521	1205	2931	3521
R^2	0.198	0.239	0.228	0.132	0.239	0.241

Note: We replaced the number of the authorization of green patents with all three types of green patents (the number of the authorization of green invention patents, the authorization of green utility patents, the application of total green patents), the regression results are presented in Column (1), (2) and (3), respectively; Column (4) displays the empirical results of using ISO 14001 as dependable variable; in column (5), the independent variable is lagged 1 year, the estimation results are exhibited in column (5); column (6) shows the estimation results when the year ×industry fixed effect is introduced. t-statistics are presented in parentheses and are calculated on the basis of standard errors clustered at the firm level. *** ,** , and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

APPENDIX C: ROBUSTNESS TESTING II: RESULTS OF DID REGRESSION

Variable	GI
DID	0.0422***
	(0.0126)
CVs	*YES*
Year	*YES*
Firm	*YES*
_cons	-0.7764***
	(0.1444)
N	21643
R^2	0.048

Note: t-statistics are presented in parentheses and are calculated on the basis of standard errors clustered at the firm level. *** ,** , and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

APPENDIX D: HETEROGENEITY ANALYSIS

	Panel A: Property rights		*Panel B:* Geographic locations		
Variable	SOEs	NSOEs	Eastern regions	Central regions	Western regions
	(1)	(2)	(3)	(4)	(5)
GF	0.0439**	0.0223	0.0527***	0.2895***	-0.0033
	(0.0208)	(0.0151)	(0.0154)	(0.1046)	(0.0810)
CVs	*YES*	*YES*	*YES*	*YES*	*YES*
Year	*YES*	*YES*	*YES*	*YES*	*YES*
Industry	*YES*	*YES*	*YES*	*YES*	*YES*
_cons	-3.5625***	-1.4654***	-2.3544***	-3.1013***	-1.2673**
	(0.3843)	(0.3239)	(0.3675)	(0.5914)	(0.4910)
N	1666	1837	2084	809	628
R^2	0.348	0.095	0.313	0.233	0.158

Note: t-statistics are presented in parentheses and are calculated on the basis of standard errors clustered at the firm level. *** ,** , and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

AUTHOR CONTRIBUTIONS

Yalin Jiang has done the following works: conceptualization, methodology, data curation, Writing-review & editing; Fengying Wang has done Formal analysis, Methodology & Validation; Chong Guo has done conceptualization, writing-original draft; and yingyu Wu has done methodology, writing-original draft & validation.

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