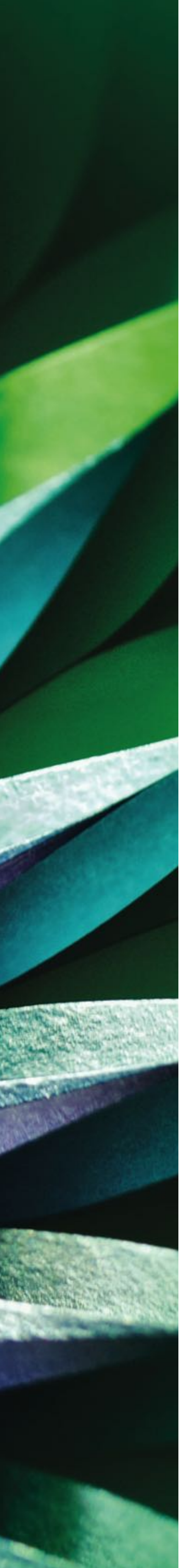

BACKGROUND PAPER

Green Finance, Innovation, and Firm Performance: Evidence from the Republic of Korea

Jihong Lee, Donghyun Park, and Shu Tian

GREEN FINANCE, INNOVATON, AND FIRM PERFORMANCE: EVIDENCE FROM THE REPUBLIC OF KOREA

Jihong Lee, Seoul National University
Donghyun Park, Asian Development Bank
Shu Tian, Asian Development Bank

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Abstract

Green finance, in particular green bond markets, has grown rapidly in the Republic of Korea in recent years. In this paper, we document some stylized facts about environmental, social, and governance ratings and green bonds in the Republic of Korea, using a novel firm-level dataset that includes corporate patenting information. Our evidence for 2011–2017 reveal the following. First, corporate patent stock is positively correlated with revenue, but negatively correlated with market value (Tobin's Q). Second, relative to the sample average, top environmental ratings are associated with higher output elasticity of physical capital, but lower output elasticity of knowledge capital and labor. Third, in Korean markets, firms that issue green bonds tend to be more innovative than other firms.

Keywords

green bond; environment, social, and governance; firm value; production function; innovation; research and development; patent

JEL Codes

G15, L25, O34

I. INTRODUCTION

Climate change represents arguably the single most-urgent challenge that human civilization faces today. One recent pioneering study analyzes global data and estimates that the global mortality cost of climate change could be as much as 85 deaths per 100,000 by the end of the century (Carleton et al. 2020). These figures are derived after controlling for projected economic growth and adaptation behavior. They also mask substantial heterogeneity across regions. The costs of global warming are expected to fall disproportionately on poor countries. The Task Force on Climate-Related Financial Disclosures (2017) outlined key climate-related risks, i.e., transition risks and physical risks during a low-carbon transition that have financial implications. Dafermos, Nikolaidi, and Galanis (2018) find that climate change can harm both the financial and nonfinancial sectors by weakening the fundamentals of firms.

Global responses to climate change are a classic case of market failure. Despite repeated dialogues going back as far as the Rio Summit of 1992, a binding coordinated solution continues to elude the international community. Emissions of greenhouse gases generate negative global externalities and the effort to curb emissions is a global public good. Therefore, the market fails to price the cost of pollution correctly. As global awareness of the risks associated with climate change grew, policy makers around the world are making efforts to reduce emissions in recent years. Major Asian economies, such as the People's Republic of China, Japan, and the Republic of Korea (ROK) pledged to achieve carbon neutrality.

In the absence of a supranational authority that is capable of implementing worldwide policies to tackle climate change, the spotlight is shifting toward the corporate world to lead the way. In today's closely integrated markets, goods, services, and credit flow across borders with unprecedented ease, largely via multinational corporations and banks. If these global institutions actively engage in activities that reduce greenhouse gas and other pollutants, the positive environmental impact may end up being much greater than those resulting from the actions of governments whose objectives are bound naturally by national self-interest.

Growing public awareness of climate change-related risk contributed to heightened public pressure on environmental sustainability and performance, which increases the vulnerability of businesses to carbon risk (Thompson 1998, Labatt and White 2007, and Subramaniam et al. 2015). Carbon risk can increase firms' cost of capital via higher cash-flow risks since carbon risk exposure increases firms' vulnerability to potential legal costs and reputational losses, which hurt firm performance. For example, carbon-intensive firms, because of their underinvestment in pollutant abatement, are more likely to violate environmental regulations, thereby triggering customer boycotts and lawsuits (Delmas and Toffel 2004, Habib and Bhuiyan 2017, and Brekke and Pekovic 2018).

Investors and companies are also becoming more aware of the financial implications of being socially responsible with respect to climate change. Socially responsible companies demonstrate greater resilience during systematic shocks (Lins, Servaes, and Tamayo 2017; and Albuquerque, Koskinen, and Zhang 2019) and firm-specific shocks, such as negative corporate events (Ho, Nguyen, and Vu 2020; and Aouadi and Marsat 2018). The social capital that firms build up strengthens the perception of trustworthiness among stakeholders, which pays off during a crisis when overall confidence is low and the value of trust increases. (Godfrey, Merrill, and Hansen 2009; and Lins, Servaes, and Tamayo 2017).

Against this backdrop, we examine two recent developments in the corporate world. First, since around 2000, corporate finance has become much more aware of the sustainability and societal impact of an investment in a company or business. Environmental, social, and governance (ESG) ratings have taken roots around the world, and asset managers and other financial institutions are increasingly relying on ESG ratings agencies to evaluate companies' ESG performance. For instance, responsible investment, a niche sector in the investment market, had a record inflow of more than $20 billion in 2019, four times the previous record for a calendar year. [1] Second, during the past decade, corporate green bonds have gained widespread acceptance. A green bond, first issued by the European Investment Bank in 2007, is a fixed-income instrument that is specifically earmarked to raise money for climate and environmental projects, including renewable energy, energy efficiency, and resource conservation. They also

[1] https://www.morningstar.com/articles/994219/sustainable-funds-continue-to-rake-in-assets-during-the-second-quarter.

finance the cultivation of environment-friendly technologies and the mitigation of climate change. From less than $3 billion in 2012, the total global issuance of green bonds surged to almost $160 billion in 2019.[2]

Issuing green bonds has been documented as a signaling device of environmental commitment by various stakeholders, such as managers, shareholders, clients, and society, and helps the issuer gain positive investor recognition. Investors are found to be less sensitive to financial returns, and more patient in fund flows when investing in socially responsible companies (Riedl and Smeets 2017, Białkowski and Starks 2016, Ghoul and Karoui 2017, and Flammer 2020). In capital markets, there is evidence that firms which issue green bonds experience favorable stock price reaction and improved trading liquidity (Flammer 2020, and Tang and Zhang 2020).

The costs and benefits of green bonds, which are an important instrument of green finance, have attracted extensive discussion. Some empirical studies document green bonds as having similar or lower costs compared to matched conventional bonds (Ehlers and Packer 2017, Baker et al. 2018, Hachenberg and Schiereck 2018, and Zerbib 2019). A strong environmental commitment—as evidenced by green labels, green bond certification, and independent verification—generates significant cost advantages for green bond issuers. Such issuers benefit from a yield reduction of 8 basis points relative to conventional bonds (Gianfrate and Peri 2019) and 6 basis points relative to green bonds that do not carry a third party certification (Hyun, Park, and Tian 2020). One key driver of the lower yield of green bonds is the high demand for green bonds, given the limited supply.[3] The Climate Bonds Initiative has frequently reported oversubscription for new green bond offerings in its market monitoring reports, indicating excess demand for green bonds.

Despite its growing popularity, however, the effects of green finance are still not fully understood. Are ESG criteria informative about the future financial performance of companies? Since green bond is a company-initiated signal of environmental commitment, does it convey different information from ESG ratings issued by external parties? Given the global nature of

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[2] https://www.climatebonds.net.

[3] For example, refer to the Climate Bond Initiative's *Green Bond Pricing in the Primary Market* and *Green Bonds Market 2019* at http://climatebonds.net.

climate change and other environmental issues as well as the heterogeneity of corporate social performance across countries (Cai, Pan, and Statman 2016), these questions need to be addressed in as many different contexts as possible.

In this paper, we use Korean firm-level data to analyze the relationship between green finance and firm performance. More specifically, we use the Korea Patent Data Project (KoPDP), a novel firm-level dataset recently constructed by Lee et al. (2020) to estimate the market value (Tobin's Q) and production functions of Korean firms during 2011–2017. The KoPDP dataset enables us to link a firm's market value and revenues with various proxies of its knowledge capital.[4] This is a new dimension of our study since green activities are often thought of as innovations. As such, we want to see whether green firms differ from other firms in terms of their innovation performance.

Another contribution of this paper is that this is the very first study to compare two different types of ESG identification mechanisms, i.e., ESG rating from third parties versus green bond issuance, which is firm-initiated environmental signaling. So far, there are no studies which attempt to understand the information content of the two ESG mechanisms. Although both ESG ratings and green bond issuance are associated with firms which are committed to ESG, they may convey different information.

Methodologically, our market value estimation model follows the framework of Hall, Jaffe, and Trajtenberg (2005) and decomposes Tobin's Q of a firm into two stock components: research and development (R&D) per assets and patents per R&D.[5] The regression for estimating the production function follows Bloom and Van Reenen (2002), who consider patent stock as a proxy for knowledge capital in addition to standard capital and labor inputs. To understand the role of green finance, we add to these regressions a dummy for top rating in the environmental category (E) of Korea Corporate Governance Service (KCGS) and a dummy for green bond issuance from Bloomberg Green.

[4] KoPDP mirrors the seminal contributions of Hall, Jaffe, and Trajtenberg (2001 and 2005) and the NBER Patent Data Project on United States data. For European counterpart, refer to Thoma et al. (2010).
[5] For a review of the related literature, refer to Hall (2000).

Our analysis reveals the following. First, we find that, for our sample of Korean firms, only R&D intensity contributes to market value. Unlike in similar studies on samples from other countries, patents per R&D in our Korean sample show negative impact on firm value. Top environmental (E) ratings are not statistically significant in the market value regression. Interestingly, however, green bond issuances turn out to be statistically significant. Such observations are associated with lower Tobin's Q, but both R&D per assets and patents per R&D turn out to be substantially more valuable. These findings suggest that green bonds are issued by a special group of firms which may be more innovation-driven.

Second, all three regressors in the production function estimation—labor, physical capital, and knowledge capital—are significant contributors to firm revenues. The share of labor is substantially larger than the other two, implying that Korean firms remain highly labor-intensive. We find that, in the ROK, top E ratings are associated with higher output elasticity of physical capital but lower output elasticity of knowledge capital and labor compared with the sample average. Green bond issuances are associated with higher revenues but show not significantly associated with the output elasticity of the three inputs.

Overall, Korean firms that engage in green activities and receive high environmental ratings appear to be different from those which issue green bonds. In particular, green bonds tend to be issued by innovative firms whose R&D and patents are associated with higher-than-average market value. On the other hand, top environmental ratings appear to be associated with firms that are more oriented toward traditional capital, according to the production function estimation results.

Our paper contributes to the growing literature on the effects of green finance by analyzing a rich novel firm-level data set from the ROK. In particular, a recent study by Flammer (2020) finds evidence from United States (US) data that green bonds have a positive causal impact on a firm's performance and environmental rating. While we find that corporate green bonds convey meaningful information about the issuing firms, there are not yet enough data points in Korean

data to track firms' post-issuance performance and examine possible causality.[6] Other studies suggest that ESG disclosures are associated with various indicators of firm performance, including lower capital costs (e.g., Dhaliwal, Li, Tsang, and Yang 2011; and Cheng, Ioannou, and Serafeim 2014) to future financial performance (Khan, Serafeim, and Yoon 2016).[7] We contribute to this growing literature by documenting novel evidence on how green finance is related to firms' innovation performance. In addition, we produce the very first evidence of possibly different signals between two ESG signaling mechanisms: ESG rating and green bond issuance.

The rest of the paper is organized as follows. We begin by briefly discussing the state of green finance in the ROK in section II. Section III then introduces the analytical framework of our empirical estimation models, followed by a description of the data in section IV. Our main findings are reported and discussed in section V, and section VI concludes the paper.

II. GREEN FINANCE IN THE REPUBLIC OF KOREA

In this section, we document the growth of green finance in the ROK in recent years. More specifically, we briefly review the development of green bond markets, a key component of green finance, in the ROK in recent years. The ROK is one of the most successful economies of the postwar era. Sustained rapid growth based on export-oriented industrialization enabled the ROK to graduate from middle income to high income in just 23 years. During the rapid industrialization, which turned the economy into a manufacturing powerhouse, successive governments of the ROK pursued a "grow now, clean up later" growth strategy which placed a low priority on protecting the environment. However, as incomes rose, the general public's demand for a cleaner environment has grown stronger. Further, because of the slowdown of growth since the Asian financial crisis of 1997–1998,

[6] One possible channel via which green bond issuance improves firm performance is by serving to signal the firm's capability, and thus attract investment and resources. In a similar vein, the value of a start-up value was found to be correlated with various forms of potential signaling devices, such as alliances (Hsu 2004), Nobel laureates as advisors (Higgins, Stephan, and Thursby 2011), founder attributes (Burton, Sørensen, and Beckman 2002), and patents (Hsu and Ziedonis 2013; and Haeussler, Harhoff, and Mueller 2014). For an overview of the theory of signaling to overcome credit rationing, refer to Tirole (2010).

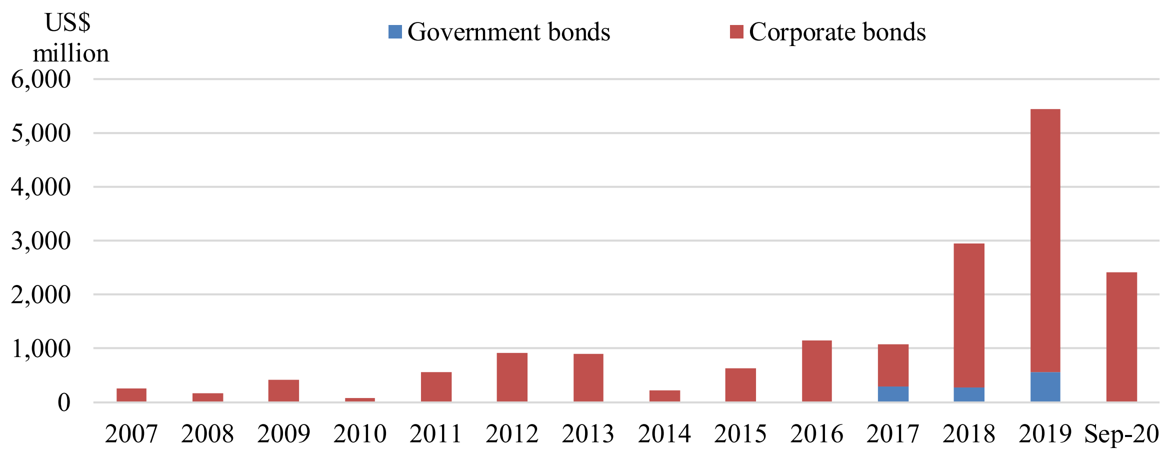
[7] For an early overview of the literature, refer to Kitzmueller and Shimshack (2012).

environmental industries are increasingly viewed as a potential engine of growth.

In response, both the government and the private sector have taken steps to promote a cleaner environment. For example, the Government of the ROK has pursued a new development paradigm that would generate growth and create jobs based on green technology and clean energy since 2008, when then-president Lee Myung-Bak announced the Korean Green Growth Initiative. In 2015, the ROK became the first country in Asia to implement an emission trading scheme. More recently, in July 2020, President Moon Jae-In's administration unveiled a Green New Deal which calls for spending W73.4 trillion won or about US$62 billion over the next 5 years. The plan is centered on significantly expanding solar and wind power generation capacity to contribute to a carbon-neutral economy by 2050. The various government initiatives have spurred the private sector to invest in green industries and technologies, such as renewable energy, LEDs (light-emitting diodes), smart power grids, and environment-friendly automobiles. For instance, the Hyundai Motor Group, one of the world's 10 largest automakers, has become a global leader in electric and hydrogen automobiles.

The government's noticeable shift toward a more active policy stance to address environmental degradation and the private sector's growing interest in environmental issues has given rise to green finance in the ROK. In particular, the ROK's green bond market has grown rapidly from a small base since the first green bonds were issued in 2007 (Figure 1). Corporate bonds account for a much larger share of the market than government bonds. Another sign of rapid market development is investment of the proceeds of green bonds in an increasingly broad range of industries. As of September 2020, the leading industries were power generation, chemicals, and automobile manufacturing, which collectively accounted for about 41% of all outstanding bonds (Table 1).

Figure 1: Green Bond Issuance in the Republic of Korea, 2007–September 2020



Source: Bloomberg LP.

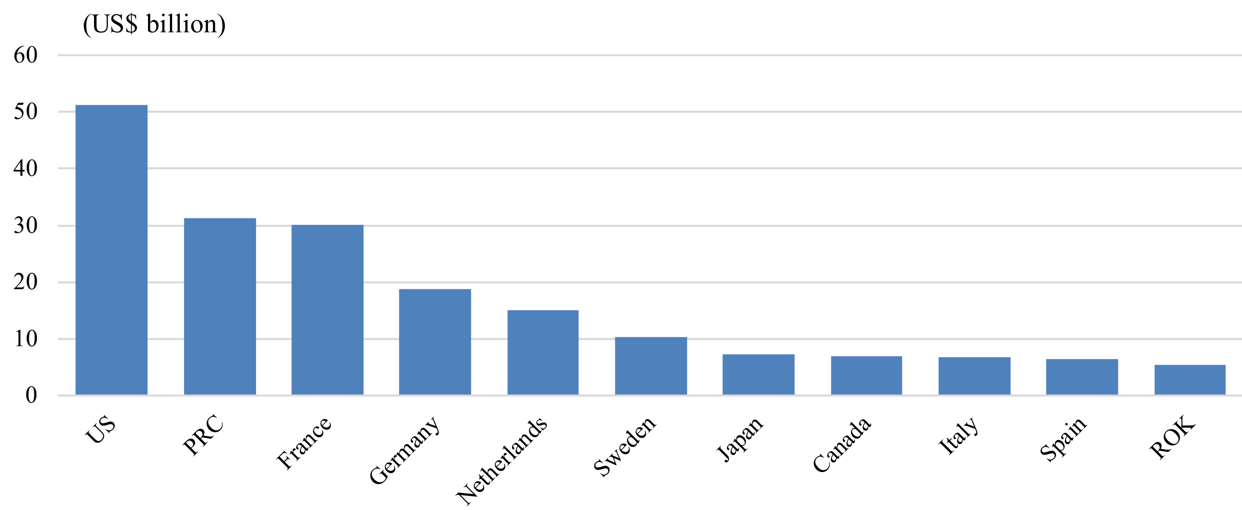
Table 1: Green Bonds Outstanding by Industry (US$)

Industry	31 December 2007	30 September 2020
Auto parts manufacturing		12,818,650
Automobile manufacturing		1,433,783,343
Banks		756,965,337
Chemicals		1,608,696,282
Commercial finance		85,457,669
Government agencies		600,000,000
Government development banks		2,898,290,681
Hardware	200,000,000	804,200,244
Industrial other		14,527,804
Metals and mining	10,690,957	—
Power generation		2,181,865,028
Real estate		200,000,000
Refining and marketing		538,383,312
Renewable energy	50,340,133	429,702,240
Software and services		8,545,767
Utilities		1,094,003,435
Waste and environment services and equipment		4,272,883
Total	**261,031,089.3**	**12,671,512,676**

— = no data
Source: Bloomberg LP.

Green bond market development has benefited from a number of conducive factors. Above all, the ROK has large and active markets for both government and corporate bonds, supported by active trading and a strong regulatory and market infrastructure. By the end of September 2020, the ROK's total bond market surpassed W2,600 trillion or US$2.2 trillion. Other factors which bode well for continued rapid growth of the Korean green bond market are a robust pipeline of bankable projects associated with a world-class manufacturing sector, strong investor base, and a supportive policy environment. On the other hand, barriers to bond market development include lack of market awareness from issuers, lack of market awareness among investors, and lack of market guidance or standards on the actual greenness of bonds. Finally, it should be noted that, although the ROK's green bond market has been developing rapidly, it is still relatively small in the international context (Figure 2). This suggests that there is plenty of scope for further growth in the future, especially since both the government and the private sector seem committed to a greener growth paradigm.

Figure 2: Amount of Green Bonds Issued, Selected Countries, 2019



PRC = People's Republic of China, ROK = Republic of Korea, US = United States.
Source: Climate Bonds Initiative (2019), Green Bonds Global State of the Market 2019.

III. ANALYTIC FRAMEWORK

In this section, we describe the analytic framework of our empirical estimation models. In particular, we describe how we estimate market value and production function.

A. Market Value

We first consider the linear and additively separable market value equation proposed by Griliches (1981): for firm i and time t,

$$V_{it} = \alpha_t (A_{it} + \beta_t K_{it})^{\sigma}, \tag{1}$$

where V_{it} is the market value; A_{it} is the stock of physical assets; K_{it} is the stock of knowledge assets; α_t represents the shadow value of all assets, equalized across firms; β_t represents the shadow value of knowledge assets relative to physical assets; and σ is a parameter representing scale effects.

Assuming constant returns to scale (i.e. $\sigma = 1$) and taking logarithm of (1), we derive an equation for Tobin's Q:[8]

$$\log Q_{it} = \log\left(\frac{V_{it}}{A_{it}}\right) = log\alpha_t + \log\left(1 + \beta_t \frac{K_{it}}{A_{it}}\right). \tag{2}$$

Following Hall, Jaffe, and Trajtenberg (2005), we proxy the knowledge–physical capital ratio, $\frac{K_{it}}{A_{it}}$, using R&D and patent stock variables and estimate the equation below:

$$\log Q_{it} = log\alpha_t + \log\left(1 + \beta_1 \frac{RD_{it}}{A_{it}} + \beta_2 \frac{PAT_{it}}{RD_{it}} + \varepsilon_{it}\right), \tag{3}$$

where α_t is the fixed effect vector for years, RD_{it} is the stock of R&D expenditure by firm i up to and including time t, and PAT_{it} is the stock of granted patents of firm i whose application dates are up to and including time t.[9] R&D expenditure reflects the firm's overall innovation effort while patenting measures the *success* of the effort. We sometimes refer to *RD/A* as R&D intensity and *PAT/RD* as R&D productivity.

[8] There other estimation models for Tobin's Q (e.g., Gompers, Ishii, and Metrick 2003). Our focus is on the contribution of knowledge capital.

[9] Because of the time lag between a patent's application and grant dates, the application date better captures the time at which innovation occurs.

The stock variables are computed as follows. For a given stock X_t at time $t > 0$, let x_t denote the corresponding *flow*. Then, we can recursively define X_t as

$$X_t = (1 - \delta)X_{t-1} + x_t,$$

where $\delta \in (0, 1)$ is the depreciation rate and $X_0 = x_0$ is the initial value. For RD_{it} and PAT_{it}, the flow terms are simply the R&D expenditure spent by and the number of patents granted to firm i in period t.

To allow for heterogeneity across firms, and specifically to examine whether green firms are systematically different from other firms, we modify (3) by adding a dummy and corresponding interaction terms:

$$\log Q_{it} = \ log\alpha_t + \eta * \log TOP_{it} + \log\left(1 + \beta_1 \frac{RD_{it}}{A_{it}} + \beta_2 \frac{PAT_{it}}{RD_{it}}\right) +$$
$$\gamma_1 TOP_{it} * \frac{RD_{it}}{A_{it}} + \gamma_2 TOP_{it} * \frac{PAT_{it}}{RD_{it}} + \varepsilon_{it} \qquad (4)$$

where TOP_{it} is the dummy variable which takes value of 1 or 0, depending on whether firm i issues green bonds or receives high ESG rating in year t.

B. Production Function

The other model analyzed in this paper is the following Cobb-Douglas production function used by Bloom and Van Reenen (2002). For firm i and year t,

$$R_{it} = \varphi_{it}\, N_{it}^{B_1} K_{it}^{B_2} G_{it}^{B_3} \qquad (5)$$

where R_{it} is real sales, φ_{it} is the total factor productivity parameter, N_{it} and K_{it} are the levels of employment and capital respectively, and G_{it} is the knowledge stock. Taking logarithm and assuming $\varphi_{it} = \exp(\alpha_i + \alpha_t + \varepsilon_{it})$, we have the following regression model:

$$\log R_{it} = \alpha_i + \alpha_t + \beta_1 \cdot \log N_{it} + \beta_2 \cdot \log K_{it} + \beta_3 \cdot \log G_{it} + \varepsilon_{it}, \qquad (6)$$

where α_i is the fixed effect vector for firms and α_t fixed effect vector for years. The coefficient on each input measures the corresponding output elasticity.

Similar to (4), we proxy G by patent stock PAT and add the TOP dummy as follows:

$$\log R_{it} = \alpha_i + \alpha_t + \eta \cdot TOP_{it} + \beta_1 \cdot \log N_{it} + \beta_2 \cdot \log K_{it} + \beta_3 \cdot \log G_{it} + \gamma_1 \cdot \log N_{it} \times TOP_{it} + \gamma_2 \cdot \log K_{it} \times TOP_{it} + \gamma_3 \cdot \log G_{it} \times TOP_{it} + \varepsilon_{it.} \quad (7)$$

IV. DATA

Our analysis is based on the KoPDP dataset recently constructed by Lee et al. (2020). The project merges DataGuide 5.0., a Korean firm-level financial database provided by FnGuide, with patent data from the Korean Intellectual Property Office (KIPO) and the US Patent and Trademark Office (USPTO).

KoPDP provides access to the entire universe of patenting information from KIPO dating back to 1948—over 2.5 million patent applications and more than 1.5 million granted patents, with a lag of about 2.5 years between the application and grant dates. There is also information on patents granted by USPTO for patents whose first assignees are located in the ROK. DataGuide 5.0 offers accounting and financial information on more than 50,000 listed and non-listed Korean firms since 1983.

The main achievement of KoPDP is to match the name of the firm in DataGuide 5.0 with the name of the patent assignees in KIPO and USPTO. The resulting panel contains more than 14,000 listed and non-listed Korean firms matched with their Korean and US patents, along with accounting and financial information. More than 45% of all sample KIPO patents and 87% of US patents assigned to Korean assignees are matched.

From the KoPDP database, we construct a sample for 2011–2017. The sample includes all listed and non-listed, all manufacturing and non-manufacturing, and all patenting and non-patenting firms. For patenting firms, we consider only patents granted by KIPO. We do not use overseas patenting information for two reasons. First, as reported by Lee et al. (2020), only a small number of Korean firms obtain global patents. Second, for firms that do obtain global patents, there is a

duplication issue since each innovation has to be patented separately for each jurisdiction. Because of the time lag between patent application and grant, patenting information beyond year 2017 is likely to be incomplete.

From the nonconsolidated financial statement provided by DataGuide 5.0, we use total revenues to proxy R, total tangible asset to proxy both A and K, and total employment number to proxy N in the regression equations presented above. All nominal variables are deflated with the Bank of Korea gross domestic product deflator with 2010 as the base year. The unit of R&D spending and other monetary variables is million won.

The two stock variables, RD and PAT, are calculated with a 30% depreciation rate and the origin value is set for the year 2000. The initial R&D stock is calculated by dividing the first year's R&D expense by the sum of the depreciation rate (30%) and the pre-sample growth rate of R&D, assumed to be 8% as in Hall (1990). Patent stock takes the number of applications granted by KIPO as a flow, sorted by the date of application, not the date of grant.

Tobin's Q is the market value divided by the replacement cost of capital. As in Hall, Jaffe, and Trajtenberg (2005), the market value and the replacement cost of capital are calculated as follows:

Market Value = Market Capitalization of Common Stock and Preferred Stock
+ Non-current Liability
+ (Current Liability - Current Asset) + Inventory

Replacement Cost = Non-current Asset + Inventory

We proxy the market capitalization by the 52-week average of market capitalization.

Table 2 summarizes basic descriptive statistics of the main variables used in the empirical analysis. Missing values in DataGuide 5.0 are not counted, except for RD for which missing value is replaced with zero. Patent count can also be zero in the case of zero R&D stock. In these cases, following HJT, we treat the corresponding PAT/RD variable as zero and later include a

dummy in the regression.[10] All the variables exhibit skewness. For the two knowledge stocks *RD* and *PAT*, as well as the ratios *RD/A* and *PAT/RD*, the mean-median difference is extreme.

Table 2: Summary Statistics

Variables	Count	Mean	50th percentile	Minimum	Maximum	Std. dev.
R (mil KRW)	67,110	204,776.2	25,027.97	-10,804.07	1.53e+08	1,973,208
Q	9,787	2.249846	1.212954	-2.483478	632.0826	8.574257
A (mil KRW)	67,110	83,612.42	8,652.918	0	5.79e+07	1,026,144
N	12,137	916.6459	230	0	10,1970	3,759.71
RD (mil KRW)	102,991	5219.06	15.06023	0	3.65e+07	266,626.8
PAT	102,991	7.558972	0.686	0	12,214.67	128.2146
RD/A (mil KRW)	66,850	14.89254	0.0172089	0	240,632.8	1,375.793
PAT/RD	62,367	1.215064	0.0022993	0	2,486.766	27.71833

Source: Authors' computation.

From data provided by Bloomberg, Green, we identify 31 firm-year observations of green bond issuance in the ROK between 2011 and 2017, associated with 17 distinct firms. ESG ratings are taken from KCGS, which provided ESG ratings since 2011. KCGS publishes an annual rating for each of the three categories: environmental (E), social (S), and governance (G), together with an overall rating (ESG). KCGS evaluates all Korea Composite Stock Price Index (KOSPI)-listed companies and selected Korean Securities Dealers Automated Quotations (KOSDAQ) companies, more than 900 companies in total. While the initial evaluation is done using publicly available sources, the companies can also provide their own feedback for revision. The distribution of firm-year observations of ESG ratings during 2011–2017 is given in Table 3.

[10] The number of such observations is 40,624.

Table 3: Environmental, Social, and Governance Ratings

Grade	E	S	G	ESG
A+	39	93	55	33
A	279	265	174	221
B+	777	539	632	523
B and below	2,648	2,983	3,110	3,078
Total	3,743	3,880	3,977	3,855

Source: Bloomberg LP.

In our baseline analysis, we consider three definitions of the dummy TOP_{it}. It takes value of 1 whenever firm i either (i) obtains A+ rating in the Environmental category (E1), (ii) obtains A+ or A rating in the Environmental category (E2), or (iii) issues green bonds (GB). Note that E1 is similar to GB in terms of the number of observations. In the Appendix, we report the results from taking A+ ratings in the remaining ESG categories as the dummy (S, G, and ESG) (Tables A1 and A2).

V. EMPIRICAL RESULTS

In this section, we report and discuss our empirical results. In our regressions, we include only firm-year observations that fully report R, N , and A. Standard errors are two-way clustered by firm and year (Petersen 2009; and Cameron, Gelbach, and Miller 2011).

A. Market Value

We estimate the market value equations (3) and (4) using nonlinear least squares on 1,607 listed firms and 9,707 firm-year observations for the period 2011–2017. All regressions include a complete set of year dummies.[11]

[11] For estimating (3) and (4), as in HJT, we do not include firm fixed effects. R&D decisions typically change slowly and are highly correlated with permanent individual traits.

The results are presented in Table 4. Column (1) reports the regression results with only *RD/A* and *PAT/RD* as regressors, together with the dummy for zero R&D stock. Columns (2) and (3) report the estimation results with the two environmental rating dummies E1 and E2, while column (4) reports the results with the dummy for green bond issuance (GB). Across all regressions, the dummy for zero R&D stock is negative and statistically significant, which indicates that such observations are associated, on average, with lower market value than the rest of the sample.

The goodness of fit is relatively low, with adjusted R^2 at about 0.17 for all the specifications. This suggests that there are many factors other than knowledge capital that determine firm value in the ROK.

Table 4: Market Value

	(1)	(2)	(3)	(4)
D(RD=0)	-0.270***	-0.271***	-0.273***	-0.270***
	(0.0481)	(0.0481)	(0.0488)	(0.0484)
RD/A	0.0108	0.0108	0.0102	0.0108
	(0.0068)	(0.0068)	(0.0065)	(0.0084)
PAT/RD	-0.000243***	-0.000243***	-0.000245***	-0.000243***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
E1		0.0731		
		(0.1944)		
E1×RD/A		-0.0957		
		(0.2515)		
E1×PAT/RD		-15.94		
		(13.0512)		
E2			-0.145	
			(0.1271)	
E2×RD/A			0.105	
			(0.1039)	
E2×PAT/RD			5.935	
			(14.4760)	
GB				-0.488**
				(0.1639)
GB×RD/A				1.709*
				(0.7891)
GB×PAT/RD				36.25
				(20.8462)
Number of firms	1,607	1,607	1,607	1,607
Adjusted *R squared*	0.172	0.172	0.173	0.172
Observations	9,707	9,707	9,707	9,707

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author estimates.

Looking at column (1), we first observe that the coefficient for R&D intensity (*RD/A*) is positive. It is not statistically significant at conventional levels, but nonetheless more than one standard deviation away from zero. Interestingly, the coefficient for R&D productivity (*PAT/RD*) is negative and statistically significant. This negative association between patents and market value stands in sharp contrast with other similar studies (e.g., Hall, Jaffe, and Trajtenberg 2005). On average, it implies that, for Korean firms, patents do not translate into firm value.

In column (2), we report the results from adding E1 dummy for observations with A+ ratings in the environmental category. *PAT/RD* remains significantly and negatively correlated with Tobin's Q and the coefficient for *RD/A* is positive and greater than one standard deviation. However, none of the coefficients for the dummy and interaction terms are significant at conventional levels. While the dummy coefficient is positive, the coefficients for both interactions terms are negative. In particular, the coefficient for $E1 \times PAT/RD$ is slightly higher than one standard deviation. These observations suggests that the firm value contribution of *RD/A* and *PAT/RD* for firms scoring A+ environmental ratings may be less than that of the other firms.

In column (3), we expand the definition of top E ratings to include A as well as A+ ratings. We observe the same results for *RD/A* and *PAT/RD* as before. The dummy coefficient continues to be statistically insignificant, but the sign is now negative. Given the positive corresponding figure in column (2), this suggests that an A environmental rating is associated with less-than-average market value in our sample. Looking at the interaction terms, both *RD/A* and *PAT/RD* are now positive although insignificant.

Last but not least, the dummy for green bond issuance (GB) turns out to have statistically significant effects in terms of both level and slope of the regression. The estimated coefficient for GB dummy is negative, indicating that green bond issuance is associated with lower Tobin's Q compared to the rest of the sample. Interestingly, the estimated coefficients for interaction with both *RD/A* and *PAT/RD* are highly positive, implying that not only R&D intensity but also R&D productivity has a positive impact on market value. The coefficient for $GB \times RD/A$ is significant at the 10% level. In fact, the value contribution of these regressors for green bond-issuing firms is so much stronger than the rest that the GB dummy appears to be selecting a group of special firms. More precisely, our findings suggest that green bonds may be favored by technology-oriented firms.

Let us summarize our findings. Patents turn out to be negatively correlated with market value in our sample of Korean firms. Top environmental ratings appear to convey no statistically

significant information about the market value of a firm or its innovation-related indicators. In contrast, green bond issuance is associated with a lower market value, but the contribution of knowledge capital for the corresponding firms is substantially larger than the rest of the sample observations. These findings suggest that green bonds may be favored by a certain type of technology-oriented firms.

B. Production Function

Table 5 presents the results from estimating the production function in (5) and (7). We perform ordinary least square estimation on 1,863 listed firms and 11,221 firm-year observations for the period 2011–2017. The sample size differs from the Tobin's Q analysis because of the inclusion of some non-listed firm observations. All equations here include a complete set of firm and year dummies. The explanatory power of our model is very high compared to the market value model, with adjusted R^2 of 0.945 in all specifications.

Table 5: Production Function

	(1)	(2)	(3)	(4)
Log Patent Stock	0.0334**	0.0335**	0.0337**	0.0326**
	(0.0117)	(0.0116)	(0.0114)	(0.0118)
Log Asset Tangible	0.0852***	0.0852***	0.0845***	0.0855***
	(0.0214)	(0.0214)	(0.0208)	(0.0215)
Log Employment	0.531***	0.531***	0.532***	0.531***
	(0.0450)	(0.0450)	(0.0455)	(0.0451)
E1		-0.266		
		(0.582)		
E1 × Log Patent Stock		-0.0491		
		(0.0330)		
E1 × Log Asset Tangible		0.103		
		(0.0605)		
E1 × Log Employment		-0.107		
		(0.0621)		
E2			-0.129	
			(0.847)	
E2 × Log Patent Stock			0.00200	
			(0.0200)	
E2 × Log Asset Tangible			0.0834	
			(0.106)	
E2 × Log Employment			-0.128	
			(0.110)	
GB				1.010***
				(0.190)
GB × Log Patent Stock				0.0622
				(0.0611)
GB × Log Asset Tangible				-0.0954
				(0.108)
GB × Log Employment				-0.0000562
				(0.204)
#Firms	1,863	1,863	1,863	1,863
Adjusted R^2	0.945	0.945	0.945	0.945
Observations	11,221	11,221	11,221	11,221

Note: Standard errors are in parentheses.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Author estimates.

Across all specifications, from column (1) to column (4), the coefficient estimates on capital and employment, as well as knowledge (patent) stock, are all positive and significant at the 1% level. In each specification, the coefficient for employment (about 0.53) is substantially higher than that for tangible assets (about 0.085) or patent stock (about 0.033), suggesting that Korean firms are still highly labor-intensive. Physical capital is more important than knowledge capital. The coefficient estimate on patent stock means that a doubling of the patent stock would result in a 3% increase in total factor productivity.

Looking at the effects of top E ratings and green bond issuance in columns (2)–(4), we find that only GB dummy has statistically significant impact at conventional levels. Green bond issuance is associated with higher revenues than the sample average. Though statistically insignificant at conventional levels, the regression results with E1 dummy report coefficient estimates on all three interaction terms that are more than one standard deviation from zero. Compared to the rest of sample, green bond issuance is associated, on average, with higher output elasticity of physical capital but lower output elasticity of knowledge capital and labor. In other words, top E-rated firms tend to exhibit higher physical capital–labor ratio than other firms in the ROK. They also rely less on knowledge capital. Though statistically less relevant, this pattern is also observed when we extend the dummy definition to include A ratings. However, green bond issuance is associated with higher output elasticity of knowledge capital. This is consistent with the previous findings on market value.

VI. CONCLUDING OBSERVATIONS

Green finance is gaining global recognition in recent years. Motivated by this trend, we document some stylized facts about ESG ratings and green bonds in the ROK, using a novel firm-level dataset that includes corporate patenting information. Our evidence from 2011 to 2017 reveals that, relative to the sample average, top environmental ratings in the ROK are associated with higher output elasticity of physical capital but lower output elasticity of knowledge capital and labor. At the same time, Korean markets value the R&D and patents of firms that issue green bonds significantly more than that of other firms.

Overall, in the ROK, firms that engage in green activities and receive high environmental ratings appear to be different from those which issue green bonds. In particular, green bonds tend to be issued by innovative firms whose R&D and patents are associated with higher-than-average market value. On the other hand, top environmental ratings appear to be associated with firms that are more oriented toward traditional capital, according to our production function estimation results.

It is worth noting that environmental ratings are provided by third party agencies and, therefore, essentially represent a screening device. In contrast, green bond issuance is a decision made by the firm itself. Indeed, one possible channel connecting green bonds with innovative firms is that innovative firms may find it worthwhile to engage in costly signaling via green bonds. It is also possible that innovative firms, especially those in green technologies, may find it cheaper to issue green bonds than other firms, as evidenced by a lower bond yield compared to similar conventional bonds (Ehlers and Packer 2017, Baker et al. 2018, and Zerbib 2019). In addition, innovative firms may benefit further since issuing green bonds gains positive investor recognition (Tang and Zhang 2020), less return-sensitive investments (Ghoul and Karoui 2017, Białkowski and Starks 2016, and Riedl and Smeets 2017) and long-term investments (Flammer 2020).

Our methodology is descriptive in nature and does not provide a causal interpretation for the observed association between high environmental ratings and green bond issuance, on the one hand, and market value and revenues, on the other. Indeed, identifying the underlying cause of our findings poses an interesting and significant future research questions. Do environment-friendly corporate activities translate into greater use of capital and higher revenue, or is it that high- revenue, capital-intensive companies tend to obtain better E ratings? Does issuing green bonds increase the value of R&D investments and patents? Green finance is still relatively young in the ROK. As more data become available, we expect further studies to tackle these questions.

APPENDIX

We also ran the two regressions with the other categories of environmental, social, and governance (ESG) rating: S, G, and ESG. Only A+ ratings are considered for the dummy. Tables A1 and A2 contain the estimation results. In Table A1, the noteworthy observation is that the coefficient for the interaction term with *PAT/RD* is all negative and significant. In Table A2, none of the dummy coefficients reports statistical significance, with their signs offering rather different pictures of production mix for top-rated firms across the categories.

Table A1: Market Value: Social; Governance; and Environmental, Social, and Governance

	(1)	(2)	(3)	(4)
D(RD=0)	-0.270***	-0.271***	-0.271**	-0.271***
	(0.0481)	(0.0482)	(0.0881)	(0.0481)
RD/A	0.0108	0.0108	0.0108	0.0108
	(0.0068)	(0.0068)	(0.0193)	(0.0068)
PAT/RD	-0.000243***	-0.000243***	-0.000243*	-0.000243***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
S		-0.0165		
		(0.1452)		
S×RD/A		-0.0185		
		(0.0246)		
S×PAT/RD		-0.0698**		
		(0.0211)		
G			0.159	
			(0.2648)	
G×RD/A			-0.0431	
			(0.0920)	
G×PAT/RD			-46.19***	
			(1.0165)	
ESG				0.0300
				(0.1227)
ESG×RD/A				-0.0185
				(0.0196)
ESG×PAT/RD				-1.329***
				(0.3108)
Number of firms	1,607	1,607	1,607	1,607
Adjusted *R squared*	0.172	0.172	0.172	0.172
Observations	9,707	9,707	9,707	9,707

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author estimates.

Table A2: Production Function: Social; Governance; and Environmental, Social, and Governance

	(1)	(2)	(3)	(4)
Log Patent Stock	0.0334**	0.0333**	0.0338**	0.0335**
	(0.0117)	(0.0115)	(0.0118)	(0.0117)
Log Asset Tangible	0.0852***	0.0839***	0.0854***	0.0852***
	(0.0214)	(0.0204)	(0.0215)	(0.0214)
Log Employment	0.531***	0.532***	0.531***	0.531***
	(0.0450)	(0.0459)	(0.0450)	(0.0451)
S		-0.217		
		(0.588)		
S × Log Patent Stock		0.0344		
		(0.0253)		
S × Log Asset Tangible		0.135		
		(0.134)		
S × Log Employment		-0.222		
		(0.174)		
G			1.253	
			(0.661)	
G × Log Patent Stock			0.0107	
			(0.0210)	
G × Log Asset Tangible			-0.0663	
			(0.0481)	
G × Log Employment			-0.0442	
			(0.106)	
ESG				0.0991
				(0.284)
ESG × Log Patent Stock				-0.0205
				(0.0266)
ESG × Log Asset Tangible				-0.0243
				(0.0332)
ESG × Log Employment				0.0407
				(0.0744)
Number of firms	1,863	1,863	1,863	1,863
Adjusted *R squared*	0.945	0.945	0.945	0.945
Observations	11,221	11,221	11,221	11,221

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author estimates.

REFERENCES

Albuquerque, R., Y. Koskinen, and C. Zhang. 2019. Corporate Social Responsibility and Firm Risk: Theory and Empirical Evidence. *Management Science*. 65 (10). pp. 4451–4469.

Aouadi, A. and S. Marsat. 2018. Do ESG controversies matter for firm value? Evidence from international data. *Journal of Business Ethics* 151, no. 4: pp. 1027–1047.

Baker, M., D. Bergstresser, G. Serafeim, and J. Wurgler. 2018. Financing the Response to Climate Change: The Pricing and Ownership of US Green Bonds. *NBER Working Paper*. No. 25194. Cambridge, Massachusetts: National Bureau of Economic Research (NBER).

Białkowski, J. and L.T. Starks. 2016. SRI Funds: Investor Demand, Exogenous Shocks, and ESG Profiles. *BlackRock Research Conference*. San Francisco. 6 January.

Bloom, N. and J. Van Reenen. 2002. Patents, real options and firm performance. *The Economic Journal*. 112(478), C97-C116.

Bloomberg LP database, accessed 15 January 2021.Brekke, K. A. and S. Pekovic. 2018. Why are firms environmentally responsible? A review and assessment of the main mechanisms. *International Review of Environmental and Resource Economics* 12(4), pp. 355–398.

Burton, M. D., J. B. Sørensen, and C. M. Beckman. 2002. Coming from good stock: Career histories and new venture formation. Working paper.

Cai, Y., C. H. Pan, and M. Statman. 2016. Why do countries matter so much in corporate social performance? *Journal of Corporate Finance*. 41, pp. 591–609.

Cameron, A. C., J. B. Gelbach, and D. L. Miller. 2011. Robust inference with multiway clustering. *Journal of Business & Economic Statistics*. 29(2), pp. 238–249.

Carleton, T. A., A. Jina, M. T. Delgado, M. Greenstone, T. Houser, S. M. Hsiang, A. Hultgren, R. E. Kopp, K. E. McCusker, I. B. Nath, J. Rising, A. Rode, H. K. Seo, A. Viaene, J. Yuan, A. T. Zhang, and J. Rising. 2020. *Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits* (No. w27599). NBER.

Cheng, B., I. Ioannou, and G. Serafeim. 2014. Corporate social responsibility and access to finance. *Strategic Management Journal*. 35(1), pp. 1–23.

Dafermos, Y., M. Nikolaidi, and G. Galanis. 2018. Climate Change, Financial Stability, and Monetary Policy. *Ecological Economics*. 152. pp. 219–234.

Delmas, M. and M. W. Toffel. 2004. Stakeholders and environmental management practices: an institutional framework. *Business Strategy and the Environment*. 13(4), pp. 209–222.

Dhaliwal, D. S., O. Z. Li, A. Tsang, and Y. G. Yang. 2011. Voluntary nonfinancial disclosure and the cost of equity capital: The initiation of corporate social responsibility reporting. *The Accounting Review*. 86(1), pp. 59–100.

Ehlers, T. and F. Packer. 2017. Green Bond Finance and Certification. *BIS Quarterly Review*, pp. 89–104.

Flammer, C. 2020. Corporate Green Bonds. *Journal of Financial Economics*. https://ssrn.com/abstract=3125518.

Ghoul, S. and A. Karoui. 2017. Does Corporate Social Responsibility Affect Mutual Fund Performance and Flows? *Journal of Banking and Finance*. 77 (C). pp. 53–63.

Gianfrate, G. and M. Peri. 2019. The Green Advantage: Exploring the Convenience of Issuing Green Bonds. *Journal of Cleaner Production*. 219. pp. 127–35.

Godfrey, P.C., C.B. Merrill, and J.M. Hansen. 2009. The Relationship between Corporate Social Responsibility and Shareholder Value: An Empirical Test of the Risk Management Hypothesis. *Strategic Management Journal*. 3, pp.. 425–445.

Gompers, P., J. Ishii, and A. Metrick. 2003. Corporate governance and equity prices. *The Quarterly Journal of Economics*. 118(1), pp. 107–156.

Griliches, Z. 1981. Market value, R&D, and patents. *Economics Letters*, 7(2), pp. 183–187.

Habib, A. and M. B. U. Bhuiyan. 2017. Determinants of monetary penalties for environmental violations. *Business Strategy and the Environment*. 26(6), pp. 754–775.

Hachenberg, B. and D. Schiereck. 2018. Are Green Bonds Priced Differently from Conventional Bonds? *Journal of Asset Management*. 19 (6). pp. 371–383.

Haeussler, C., D. Harhoff, and E. Mueller. 2014. How patenting informs VC investors–The case of biotechnology. *Research Policy*. 43(8), pp. 1286–1298.

Hall, B. H. 1990. *The manufacturing sector master file: 1959–1987* (No. w3366). NBER.

Hall, B. H. 2000. Innovation and Market Value, in *Productivity, Innovation and Economic Performance.* R. Barrell, G. Mason, and M. O'Mahoney (eds). Cambridge: Cambridge University Press, pp. 188–198.

Hall, B. H., A. B. Jaffe, and M. Trajtenberg. 2001. *The NBER patent citation data file: Lessons, insights and methodological tools* (No. w8498). NBER.

Hall, B. H., A. Jaffe, and M. Trajtenberg. 2005. Market value and patent citations. *The RAND Journal of Economics*, pp. 16–38.

Higgins, M. J., P. E. Stephan, and J. G. Thursby. 2011. Conveying quality and value in emerging industries: Star scientists and the role of signals in biotechnology. *Research Policy*. 40(4), pp. 605–617.

Ho, C., H. Nguyen, and V. Vu. 2020. *The Real Effects of Environment and Social Scandals on the Corporate Sector*. SSRN: 3601616.

Hsu, D. H. 2004. What do entrepreneurs pay for venture capital affiliation? *The Journal of Finance*. 59(4), pp. 1805-1844.

Hsu, D. H. and R. H. Ziedonis. 2013. Resources as dual sources of advantage: Implications for valuing entrepreneurial-firm patents. *Strategic Management Journal*. 34(7), pp. 761–781.

Hyun, S., D. Park, and S. Tian. 2020. The Price of Going Green: The Role of Greenness in Green Bond Markets. *Accounting & Finance*. 60 (1). pp. 73–95.

Khan, M., G. Serafeim, and A. Yoon. 2016. Corporate sustainability: First evidence on materiality. *The Accounting Review*. 91(6), pp. 1697–1724.

Kitzmueller, M. and J. Shimshack. 2012. Economic perspectives on corporate social responsibility. *Journal of Economic Literature*. 50(1), pp. 51–84.

Labatt, S. and R.R. White. 2007. *Carbon Finance: the Financial Implication of Climate Change*. Hoboken: John Wiley & Sons, pp.1–2.

Lee, J., H. Lim, S., Kim, K., Song, and J. Y. Jung. 2020. Korea Patent Data Project (KoPDP): Contents and Methods. *The Korean Economic Forum*. 12(4), pp. 125–181.

Lins, K.V., H. Servaes, and A. Tamayo. 2017. Social Capital, Trust, and Firm Performance: The Value of Corporate Social Responsibility during the Financial Crisis. *The Journal*

of Finance. 72 (4): pp. 1785–1824.

Petersen, M. A. 2009. Estimating standard errors in finance panel data sets: Comparing approaches. *The Review of Financial Studies*. 22(1), pp. 435–480.

Riedl, A. and P. Smeets. 2017. Why do investors hold socially responsible mutual funds? *The Journal of Finance*. 72(6), pp. 2505–2550.

Subramaniam, N., D. Wahyuni, B.J. Cooper, P. Leung, and G. Wines. 2015. Integration of carbon risks and opportunities in enterprise risk management systems: evidence from Australian firms. *Journal of Cleaner Production*. 96, pp. 407–417.

Tang, D. and Y. Zhang. 2020. Do Shareholders Benefit from Green Bonds? *Journal of Corporate Finance*. Volume 61, 101427.

Task Force on Climate-Related Financial Disclosure. 2017. *Final Report–Recommendations of the Task Force on Climate-Related Financial Disclosures*. New York. https://www.fsb-tcfd.org/wp-content/uploads/2017/06/FINAL-TCFD-Report-062817.pdf.

Thoma, G., S. Torrisi, A. Gambardella, D. Guellec, B. H. Hall, and D. Harhoff. 2010. *Harmonizing and combining large datasets-An application to firm-level patent and accounting dat*a (No. w15851). NBER.

Thompson, P. 1998. Bank lending and the environment: Policies and opportunities. *International Journal of Bank Marketing*. 16. pp. 243-52.

Tirole, J. 2010. *The theory of corporate finance*. Princeton University Press.

Zerbib, O.D. 2019. The Effect of Pro-Environmental Preferences on Bond Prices: Evidence from Green Bonds. *Journal of Banking and Finance*. 98, pp. 39–60.