Do public subsidies trigger firms’ overinvestment? Evidence from the Korean renewable energy technology industry

Bongsuk Sung1 · Sang Do Park2 · Myoung Shik Choi3

Received: 21 April 2021 / Accepted: 3 August 2022 / Published online: 10 August 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract
We empirically investigate whether government subsidies result in firms’ overinvestment using unbalanced panel data from 61 renewable energy technology firms in Korea between 1991 and 2018. Considering the diagnostic test results, we build a panel vector autoregression model and test how overinvestment is influenced by research and development and non-research and development government subsidies and the interactions between subsidies, leverage, and free cash flow. We find that these subsidies do not significantly induce overinvestment by firms. In addition, non-research and development subsidies affect overinvestment positively through leverage and affect it negatively through free cash flow interactions. We also find that leverage and free cash flow do not affect overinvestment in Korea’s renewable energy technology sector directly; however, firms with positive free cash flow tend to overinvest. One factor that drives renewable energy technology firms in Korea to overinvest is external growth opportunities. We suggest various policy implications based on this study’s results.

Keywords Overinvestment · R&D subsidy · Non-R&D subsidy · Free cash flow · Leverage · Dynamic panel approach

Introduction
Funding shortages are a crucial setback for renewable energy technology (RET) firms (Mazzucato and Semieniuk 2018). Financing and investment are essential to RET firms in developing innovation and technology in many countries such as Germany, the UK, the Netherlands, Denmark, Ireland, Hungary, Slovakia, Poland, the Czech Republic, Belgium, Korea, the USA, and China (Corsatea et al. 2014; Kim et al. 2014). Financial resources tend to be channeled towards more profitable investment projects in capital markets, wherein the expected future return exclusively governs investment decisions (Peneder 2008). However, it is unclear whether the potential value of firms’ innovation activities or projects is actualized because of a variety of technological uncertainties (Jalonen 2012; Rout et al. 2009) and market uncertainties (Foxon et al. 2005; Luding et al. 2015; Meijer et al. 2007). Examples of such uncertainties include customers’ demand levels and preferences that increase the cost of and threshold for innovative activities or projects in the RET sector, which decreases the investment incentives of investors and causes funding shortages. Furthermore, since the 2008 financial crisis, the preferences of financial entities have shifted towards short-term financial products instead of long-term investments such as RET projects (Jacobsson and Karltorp 2013). With the longer payback periods and higher investment costs related to RET projects compared with non-RET projects (Zhang et al. 2012), the risks that affect the solvency and reliability of RET firms lead to reduced investment in the sector. Technology spillovers can also reduce the incentives for RET firms to innovate. When technology spillovers are high, firms are free to employ the technical and practical knowledge accumulated through other firms’
innovation activities, increasing their technological development and enhancing productivity. Therefore, it is challenging for firms with greater technology spillovers to compete using their own innovations (Hörte 2004). In this case, knowledge as a public good decreases returns on innovation, which in turn leads to underinvestment in innovation activities, including research and development (R&D) (Dechezleprêtre et al. 2017; Peneder 2008). Hoppmann (2018) demonstrates that for the solar photovoltaic technology industry, spillovers of a firm’s knowledge to other companies reduce not only any potential competitive advantages obtained through innovation, but also the focal firm’s incentive to invest in innovation activities. The asymmetric information problem also financially constrains investment in innovation (Hall 2002). Firms that plan to conduct innovation activities or projects generally possess more information about the nature, probability of success, and economic potential of these activities than prospective financiers. This creates high levels of uncertainty for prospective financiers (Akerlof 1970; Leland and David 1977). Such informational asymmetries between firms and prospective financiers could result in costly external financing for planned innovation activities or projects, or even eliminate financing completely (Myers and Majluf 1984). Consequently, this could lead to underinvestment in innovation activities or projects in the RET sector (Garrone et al. 2014; Koseoglu et al. 2013).

When funding is insufficient, public subsidies can promote RET firms’ innovation activities and technological development by alleviating debt and reducing the equity gap. This is achieved by decreasing the amount of external funding required, increasing the number of prospective financiers willing to fund projects (Takalo and Tanayama 2010; Czarnitzki 2006), and reducing the risk and raising the return on investment of RET innovation activities (Meledu and Pulina 2018). Accordingly, this can affect investors’ behavior and interests (Bürer and Wüstenhagen 2009; Zhang et al. 2016) by sending an observable signal to external investors about the quality of projects undertaken by firms (Feldman and Kelley 2006; Meuleman and De Maeseneire 2012), accelerating various RET-related entrepreneurial activities, and securing favorable conditions for the development and diffusion of RETs (Meuleman and De Maeseneire 2012; Sung and Cui 2018). Most empirical studies, such as Ang et al. (2017), Busom and Fernandez-Ribas (2008), Cerulli et al. (2016), Chang et al. (2019), Clarysse et al. (2009), Crespi et al. (2014), Dimos and Pugh (2016), Liu et al. (2019), and Zúñiga-Vicente et al. (2014), show that public support (e.g., R&D subsidies, feed-in tariffs, and quantity restrictions) not only plays an important role as an additional input, but also encourages investment. By promoting innovation, public subsidies are thus a vital driver of the sustainable development and growth of the RET sector, which consistently contributes to environmentally sound and sustainable development in society. Stainability is possible through the optimal amount of investment (Wallsten 2000; Zhang et al. 2016). Firm managers should undertake investment only when they will earn sufficient profitability (Stigler, 1963). However, managers’ investment decisions cannot always enhance profitability. According to the agency theory, managers often expand a business to seek their private interest, which may decrease the wealth of shareholders (Jensen 1986; Jensen and Meckling 1976). In this case, although it is impossible to achieve sufficient profitability and future growth opportunities are not positive, they tend to overinvest to simply scale up. Such investment can increase business risks and the cost of capital (Baker et al. 2003; Titman et al. 2004), which can deteriorate growth potential, profitability, and productivity. Furthermore, it can affect RET firms’ sustainable competitive advantage. This can shrink RET firms’ business activities, which prevents them from contributing to environmentally sound and sustainable development. Hence, it is necessary for academic researchers and policymakers to address overinvestment in RET firms because of public subsidies.

On this issue, UNEP (2013), Zeng (2015), and Zhao et al. (2011) explore investment in China’s RET firms, finding that the government’s strong support has induced the rapid growth and expansion of the solar photovoltaic industry and thus resulted in overinvestment. Some studies such as Gillingham and Sweendy (2010), Jensen (1986), Linores and Labanderia (2013), Liu et al. (2016), Mazzucato and Semieniuk (2018), and OECD (2013) point out that public support may result in firms’ overinvestment because of the inconsistencies in policy implementation between the central and local governments, policy uncertainty, excessive price guarantees, and the promotion of influential organizations. Nonetheless, empirical evidence for whether public subsidies cause overinvestment in RET firms, especially firms that produce RET-related products and components, is scarce. Thus, this study empirically tests the influences of public subsidies on RET firms’ investment levels in Korea, focusing on manufacturer of RET-related products and components. In particular, we aim to identify the relative importance of the interactions between government subsidies and sources—free cash flow and leverage—that induce overinvestment from the pecking order theory (Myers and Majluf 1984) and trade-off theory perspectives (Myers 1977). Government subsidies tend to induce favorable behavioral organizational effects toward innovation by collaborating with other firms and institutions (Busom and Fernandez-Ribas 2008; Clarysse et al. 2009; Crespi et al. 2014) and crowding in private investment (Ang et al. 2017; Chang et al. 2019; Dimos and Pugh 2016; Liu et al. 2019; Zúñiga-Vicente et al. 2014). According to the pecking order theory, firms prefer a sequential choice over funding sources for additional investments, using retained earnings, issuing debt,
and issuing equity. Therefore, public subsidies are the most desirable type of funding, as it is free capital. After receiving public subsidies, firms need additional investments. In this case, retained earnings are a desirable source of funding as it does not require additional issuance of debt or equity. However, when there are no available retained earnings to invest, more additional investment funds would be needed, or when there is conflict between managers and shareholders, managers can finance debt to seize more profitable market opportunities driven by public subsidies (Polzin et al. 2015; Wüstenhagen and Menichetti 2012), which increases debt ratio. In this process, overinvestment can occur when external funds are easily available (López-de-Foronda et al. 2019). According to the trade-off theory approach, firms try to reach their debt level that maximizes the advantage of the debt tax shield (which means equity gains are taxed, whereas interest payments can be expensed and hence are tax-advantaged) and minimize the possibility of bankruptcy. Therefore, firms try to utilize debt financing for additional investment. However, debt deteriorates the conflict between debtholders and shareholders because the debt contract makes shareholders sub-optimally invest. In this case, shareholders can use debt funds to overinvest in risky projects, so they are able to extract value from debtholders. This is because shareholders’ limited liability induces them to invest in more risky projects to create greater value (Jensen and Meckling 1976). The conflict between managers and shareholders also leads to overinvestment. When information asymmetries exist, managers may have incentives to overinvest free cash flow in unprofitable projects to acquire the monetary and non-monetary benefits associated with firms’ outward growth (Jensen 1986; Stulz 1990). When a firm increases its investment, other firms imitate the investment action of the firm, which is called herd behavior. From the perspectives of rational conformity, information cascades, social learning (Banerjee 1992; Bikchandani et al. 1998; Koetsier and Bikker 2018; Merli and Roger 2013), and organizational sociology and ecology (DiMaggio and Powell 1991), such as herding behavior of a firm, partly cause overinvestment and overproduction (Banerjee 1992; Scharfstein and Stein 1990). Based on the aforementioned points, this study explores the relative effects of the interaction between government subsidies and free cash flow and leverage on firms’ overinvestment. Our findings provide implications for future research on promoting optimal investment in RET firms through public policies to achieve environmentally sound and sustainable development in society.

The remainder of this paper is organized as follows. We present the theoretical background of the relationship between public subsidies and firms’ overinvestment in “Theoretical background”. In “Measures and data”, we measure the variables and describe the sample. We then present and interpret the results of our empirical test in “Empirical test”. Finally, we propose policy implications based on our main findings and list the limitations of this study in “Discussion and conclusions”.

Theoretical background

While public subsidies play a vital role in promoting RET firms’ innovation (Plank and Doblinger 2018; Sung 2019) by helping overcome underinvestment in innovative activities due to uncertainties related to technology and markets (Gillingham and Sweedny 2010) and spillovers (Hoppmann 2019), they may result in overinvestment (Gillingham and Sweedny 2010; Jensen 1986; Linores and Labanderia 2013; Liu et al. 2016; OECD 2013; UNEP 2013; Zeng 2015; Zhao et al. 2011). For example, the implementation of policies to address environmental externalities from either fossil fuels or renewable energy use may generate overinvestment in firms that produce RET-related products and components, such as cell, module, inverter, power control device, and other material parts used in renewable energy production equipment. Economic theory argues that when environmental externalities are not priced, fossil fuels will be overused in energy markets, and renewable energy resources will be underused. This situation does not encourage the seeking of technologies and processes that increase energy efficiency and therefore does not reduce emissions. Many countries use energy efficiency investment subsidies as a policy instrument to address such environmental externalities (Gillingham and Sweedny 2010), as the overuse of fossil fuels or underuse of renewable energy resources can be corrected by subsidizing energy markets. However, considering that more energy conservation and less investment in energy-efficient technologies may be the optimal choice, such additional subsidies may lead to overinvestment in subsidized energy-efficient technologies, including RET-related products and components.

Public subsidies to promote renewable electricity production capacity, which are part of achieving renewable energy targets and reducing dependency on fossil fuels, also have the underlying motivation of tackling environmental externalities. Such subsidies can help reduce the overuse of fossil fuels and promote the use of renewable energy, but they also increase demand for RET-related products and components. Increased demand implies enhanced market certainty, which raises the certainty of RET-related projects and RET firms and further encourages firms to proactively perform R&D activities and acquire and modernize the machinery and equipment to manufacture more RET-related products and components by overestimating the market. Furthermore, the use of feed-in tariffs that set the price of electricity from renewables too high to deploy renewable energy can lead to firms’ overinvestment and increase electricity prices, which
forces the government to readjust such tariffs (OECD 2013). Such a government reaction increases policy uncertainty and can stimulate overinvestment. Liu et al. (2016) show that when future policy to promote renewable energy production capacity is uncertain, firms tend to prioritize holding scarce resources for future purposes, which may result in overinvestment.

Governments actively respond to such firms’ investment intention by offering subsidies. As UNEP (2013), Zeng (2015), and Zhao et al. (2011), if subsidies are offered aggressively and unevenly (Mazzucato and Semieniuk 2018) to firms, areas, and technologies under these conditions, overinvestment in RET firms may result. Furthermore, when influential organizations such as UNEP and Bloomberg New Energy Finance promote RET firms, finance, including public support, tends to flow towards the areas and/or technologies that these organizations promote, which can lead to lopsided investment in and the overfinancing of RET firms in those areas and/or technologies.

Other factors may affect the overinvestment induced by public subsidies. Jensen (1986) argues that when policy intervention exists, conflicts of interests between investors and firms’ managers can exist due to agency problems, which may cause overinvestment. The differences in the policy orientation of central and local governments can relate to overinvestment in RET firms. For example, to prevent overinvestment in renewable energies, the Spanish government introduced a cap-and-floor system in 2007. However, this mechanism was not successfully implemented because local governments promoted RET investment to boost their economy (Linore and Labandaria 2013).

In addition to public subsidies, firm heterogeneity may be involved in firms’ overinvestment. Their capital structure is the most important factor that may affect firms’ investment decisions (Corsatea et al. 2014; Rout et al. 2009; Chang et al. 2019). Debt and financial constraints influence RET firms’ tangible and R&D investments (Chang et al. 2019). Pecking order theory (Myers and Majluf 1984) argues that firms favor internal over external financing and external to equity financing. Therefore, high internal capital from increasing profits reduces a firm’s need for external financing. However, after internal funds are exhausted, firms turn to external sources for financing. Jensen (1986) states that firms with both substantial internally generated funds and external funding could allocate the increase in cash flow to projects with negative net present value, leading to overinvestment. Debt financing has both advantages and disadvantages. Trade-off theory (Myers 1977) argues that firms consider the costs and benefits of additional debt and make decisions based on optimal leverage. For instance, external financing offers firms the advantage of tax benefits. However, debt financing is less likely to appeal to firms with high leverage because the potential costs are higher than the benefits, which prevents firms from overinvesting (Ahn et al. 2006; Aivazian et al. 2005; Ding et al. 2019; D’Mello and Miranda 2010).

Considering the discussion above, pivotal influences on firms’ overinvestment may include government subsidies, cash flow, leverage, and their interactions. According to Chang et al. (2019), Ding et al. (2019), Faulkender and Wang (2006), Meuleman and De Maeseneire (2012), Zhang et al. (2016), and Karpavičius and Yu (2019), growth opportunities and firm size can also be related to firms’ overinvestment. First, growth opportunities tend to add value to firms while increasing debt (Titman and Wessels 1988) and equity financing capacity (Faulkender and Wang 2006; Karpavičius and Yu 2019). Second, firm size attracts outside investors by mitigating informational asymmetries (Meuleman and De Maeseneire 2012).

Considering these points, we use the following panel regression model to test the effects of government subsidies on firms’ overinvestment. We also identify the relative importance of the interactions between government subsidies and sources that induce overinvestment—internal financing, leverage, and growth opportunities—expressed as

\[
OVERIN_{it} = \alpha + \beta X_{it-p} + \gamma Z_{it} + \eta_i + \varepsilon_{it}
\]

where \( i \) is the firm, \( t \) is the year, \( \eta_i \) is the firm-specific effect, and \( \varepsilon \) is the error term. \( OVERIN \) is a proxy for overinvestment, and \( X \) refers to government subsidies. \( Z \) represents the control variables—internal financing, leverage, growth opportunities, and firm size—that may affect the nexus between government subsidies and firms’ investment efficiency.

**Measures and data**

To determine whether firms are overinvested, the following two approaches are used in the previous studies: an above-the-median method that compares capital expenditure with the median ratio of the industry on an annual basis (e.g., Bates 2005; D’Mello and Miranda 2010; Hendershott 1996) and an estimation method that predicts the optimal investment level (e.g., Aivazian et al. 2005; Ding et al. 2019; McNichols and Stubben 2008). A median-based approach uses the median of each sample firm’s industry median investment for the same year and classifies half of the observations in the sample as an above-median investment. Therefore, it is not proper to regard these firms as overinvesting firms (Ding et al. 2019). In addition, this method cannot classify firms, sufficiently ensuring different growth opportunities when modeling overinvestment (Aivazian et al. 2005). Therefore, this study follows Ding et al.’s (2019)
estimation approach. We first estimate the following investment equation to predict the optimal investment level:  
\[
\frac{I_t}{K_i} = \alpha + \beta_1 CF_{i,t-1} + \beta_2 SG_{i,t-1} + \beta_3 FS_{i,t-1} + v_t + \epsilon_{i,t}
\]
where \(i\) is the firm; \(t\) is the time; \(f\) is fixed investments; \(K\) is real tangible fixed assets; \(CF\) is the ratio of cash flow to tangible assets; \(SG\) is sales growth; \(FA\) is firm age measured as the number of years from registration; \(FS\) is firm size measured as total assets; \(v_t\), \(v_t\), and \(v_t\) are firm-specific time-invariant, time-specific, and sector-specific components, respectively; and \(\epsilon_{i,t}\) is the error term. In the panel context, we establish a dynamic panel vector autoregression model in first difference equation. Then, we compare investment \(I/K\) with the predicted optimal level \(I/K^{*}\) obtained from the investment equation and determine whether the former is above the latter, as indicated by a positive \(\epsilon_{i,t}\), indicating possible overinvestment. \(I/K - I/K^{*}\) is the dependent variable.

The Korean government provides firms with two types of subsidies: R&D and non-R&D subsidies. R&D subsidies promote research and protect intellectual property, whereas non-R&D subsidies support the purchase and modernizing of machinery and equipment to promote technological development (Sung 2019). We measure R&D (RDS) and non-R&D (NRDS) subsidies as the ratios of RDS and NRDS received by each firm to its total assets, respectively.

We use free cash flow as a proxy for the amount of internal financing. Following the study of Ding et al. (2019), the equation to predict firms’ optimal investment levels used in this study is estimated in the absence of free cash flow and lack of a restraining influence of debt, which are expected to cause overinvestment. Within this approach, we define free cash flow \((FCF)\) as cash flow beyond what is needed for asset maintenance cost (i.e., depreciation) and the optimal investment financing and measure using the following equation:  
\[
FCF_{i,t-1} = CF_{i,t-1} - DEP_{i,t-1} - I/K^{*}_{i,t-1},
\]
where \(CF\) is the ratio of cash flow to assets, \(DEP\) is depreciation, and \(I/K^{*}\) is the optimal investment level obtained from the investment equation following Ding et al. (2019). We use the ratio of financial debt to total assets as a proxy for leverage \((LEV)\). We measure firms’ growth opportunities in two ways following Karpavičius and Yu (2019). External growth opportunities \((EGO)\) depend mainly on industry growth potential, measured as the 3-year subsector sales growth rate. Internal growth opportunities \((IGO)\) arise because of the firm’s R&D, marketing, and innovation activities. Meuleman and De Maeseneire (2012) and Karpavičius and Yu (2019) use capital and R&D expenditure, or patents, as proxies for internal growth opportunities. Capital and R&D expenditure serve as innovation inputs for creating innovation outputs such as patents and new products. Patents are a widely accepted proxy for innovation converted into business opportunities. However, they do not perfectly reflect all firm innovations because unweighted number-driven counts do not consider commercial success (Sung 2019). As capital and R&D expenditure/patents appear to be insufficient for capturing internal growth opportunities, we thus use intellectual capital, which extends beyond simple numbers to appropriately capture the variety and link between firms’ innovation processes and the resulting business opportunities. A firm’s intellectual capital represents its comprehensive learning capability that integrates R&D, innovation, marketing capabilities, and other capital expenditure (Andonova and Ruiz-Pava 2016; Bakhsha et al. 2017; Lu et al. 2010) relevant to producing value (Costa 2012). Following Roos et al. (1997) and Stewart (1997), we define intellectual capital as the firm’s intangible assets from which it can derive future benefits. We measure intellectual capital following Stewart’s (1995) return on assets metric. We measure firm size \((FS)\) as total assets in line with Ding et al. (2019) and Meuleman and De Maeseneire (2012). All variables and measurements are presented in Table 1.

Our data are based on the annual measures of each sample firm over 1991 to 2018. Because Korea does not have a standard industrial classification for the RET industry, we sample RET firms by crosschecking them against the Korean Energy Agency and KIS Value databases based on name, address, business scope, and products. Matched companies are confirmed by visiting their websites. Finally, we extract data on 61 companies from the KIS Value database for the empirical analysis. Unsuitable observations are excluded. The dataset is unbalanced, with 1014 observations. All the variables are calculated using 2010 constant prices and expressed in logarithmic form. Table shows the descriptive statistics of the sample.

About a half (50.8%) of the sample specialize in the solar energy technology (Sol) (31 firms), geothermal energy technology (Geo) (seven), and bioenergy technology (Bio) (three) subsectors, with the remaining 20 companies distributed across more than two subsectors. Overall, RET firms in Korea overinvest slightly. For each subsector, overinvestment is the highest for firms that engage in the Sol/Geo/Win (wind energy technology) subsectors followed by firms engaging in the Bio, Sol/Win, Sol/Geo/Win/Bio, and Sol/Geo subsectors. The optimal investment level is highest for firms in the Sol/Geo/Win/Bio subsector, followed by firms in the Win/Geo, Sol/Geo/Win, Sol/Geo, Bio, and Sol/Win subsectors. Regarding R&D subsidies, firms specializing in the Sol/Geo/Win/Bio subsector receive the most (KRW 0.767 billion on average), followed by firms that engage in the Sol/Geo, Sol/Win, and Sol subsectors. Firms in the Win/Geo and Bio subsectors receive considerably less R&D subsidies than those in the other subsectors. Non-R&D subsidies, listed in order of amount, are distributed to firms that engage in the Sol/Geo, Sol/Geo/Win/Bio, Sol, and Win/
Geo subsectors. The free cash flow of these firms is between 0.133 and 0.267 billion KRW on average.

Firm leverage is between 50 and 60%. In terms of industry growth, firms in the bio subsector rank first, showing a 3-year average growth of 14.52%, followed by firms in the Sol/Win, Geo, and Sol subsectors. Overall, all the subsectors demonstrate fast annual growth (above 6% on average). Annual sales growth is the highest in the geo subsector (37.6%), followed by the Sol/Geo (25.35%), Sol/Geo/Win/Bio (18.88%), Bio (12.14%), Sol (7.08%), and Sol/Geo/Win (4.17%) subsectors. The annual sales growth rates are higher than the annual sustainable growth rates for firms specializing in the Geo, Sol/Geo, Win/Geo, and Sol/Geo/Win/Bio subsectors. This finding suggests that additional growth without productivity and profitability improvements can erode financial soundness by increasing non-performing assets, ultimately lowering sustainable growth. Regarding firms in the Sol, Sol/Win, Sol/Geo/Win, and Bio subsectors, the annual sustainable growth rates are higher than the annual sales growth rates. The finding implies that management should make great efforts to determine and eliminate internal constraints to firm growth. According to Higgins (2009), it does not mean that the actual growth (sales growth) rate and sustainable growth rate should be the same or even approximately close to each other at the firm level. However, it is crucial for firms to recognize the disparity between the two rates and devise and implement practicable policy strategies to tackle it.

Figure 1 illustrates the growth rates (sales and sustainable growth) and investment levels (actual and optimal) of firms per year. We observe overinvestment in the RET sector in Korea from 1997, with higher levels of overinvestment in 2001, 2004, 2008, and 2017 driven by the investment decisions of firms affected by the strong policy drive towards energy transition in Korea. Examples include the introduction of a feed-in tariff to create a renewable energy market in 2001, the first new and renewable energy declaration in 2004, the national strategy for green growth in 2008, and the decision on the roadmap for energy transition in 2017. Korean government subsidies for RET firms under these policy drives increased after 2001, which could have induced overinvestment by attracting external private investors.
amounts and increasing trend (see Fig. 2) suggest that non-R&D subsidies may be more relevant in terms of overinvestment than R&D subsidies.

**Empirical test**

**Empirical strategy**

The empirical analysis comprises three steps. First, we conduct diagnostic tests to confirm the data characteristics. We confirm the presence of first-order autocorrelation to determine whether we should follow a static or dynamic panel approach. We also conduct tests for the presence of structural breaks in the time series and dependence between the cross-sectional units within the panel. This is important because testing for stationarity and co-movement among the variables depends on the results of these two tests. Furthermore, we diagnose homoscedasticity within the cross-sectional units. Second, we consider the characteristics of the data from the tests performed in the first step and build an empirical model to test the nexus between overinvestment, government subsidies, and the control variables. Lastly, we estimate the empirical model using a panel estimator, which is the most appropriate for this study’s sample size.

**Panel framework tests**

Before examining the characteristics of the data, we confirm that multicollinearity is not an issue in the panel data. All the independent variables meet the criterion proposed by Kennedy (1992): a variance inflation factor < 10. To review this data trait, we first conduct Wooldridge’s (2002) test, which reveals first-order autocorrelation in the panel data (F statistic = 39.179, p < 0.000). Then, considering that there are more companies (61) than the number of years in the study period (28), we use Pesaran’s (2004) cross-sectional dependence test, finding that cross-sectional dependence exists (residual mean absolute correlation = 0.243; cross-sectional dependence = 5.566). We also confirm the existence of heteroscedasticity within the cross-sectional units ($\chi^2 = 298.53, p < 0.000$).

Furthermore, we perform the cumulative sum of recursive residuals (CUSUM) and CUSUM squared (CUSUMQ) tests proposed by Brown et al. (1975) to understand whether the time series are stable over time. The two tests indicate stability in all the series except for one company from the CUSUM test and 10 from the CUSUMQ test (the results are available from the author on request). We also conduct Pesaran’s (2007) unit root test (Table 2), finding that the level variables are not stationary, whereas the first differences of all the levels of the variables are stationary. Having
established the non-stationarity of the variables, we can examine the possibility of long-term co-movement among them by conducting Westerlund’s (2007) heterogeneous panel co-integration test. However, we do not conduct this test because of the high number of covariates (> 6).

**Panel estimator and empirical evidence**

On the basis of the results of the panel diagnostic tests, we use a dynamic panel vector autoregression model in first differences to empirically explore the influence of government subsidies on overinvestment. The presence of first-order autocorrelation suggests that we should establish a dynamic model. Therefore, in the empirical model, we control for this autocorrelation by including the dependent variable in the previous period as an independent variable. The presence of unit roots suggests that we should include the first difference variables in the empirical model. One challenge is the existence of cross-sectional dependence, which inhibits producing accurate and efficient parameter estimates. Including time dummies or cross-sectionally demeaning the data can eliminate cross-sectional dependence among errors (Roodman 2009; Sarafidis et al. 2009). We create year dummy control variables to prevent cross-individual correlation.

Considering the aforementioned points, we build a panel vector autoregression model in first differences to test the relationship between government subsidies and overinvestment as follows:

\[
\Delta \text{OVERIN}_{it} = \lambda \Delta \text{OVERIN}_{it-1} + \beta \Delta X_{it-p} + \gamma \Delta Z_{it-p} + \Delta \epsilon_{it} + d_t
\]  

(2)

where \( \Delta \) is the first difference operator, \( t \) is the time; \( \text{OVERIN} \) is a vector of the logs of firms’ overinvestment. \( X \) is a vector of the logs of government subsidies, \( Z \) is a vector of the other control variables, \( \epsilon \) is a vector of idiosyncratic errors, and \( d \) is the time dummy.

Equation (2) introduces the simultaneity problem by differencing, which occurs when lagged exogenous variables correlate with the new differenced error term and heteroscedasticity of genuine errors across firms. To solve these issues, we can use both difference GMM (Arellano and Bond 1991) and system GMM (Arellano and Bover 1995; Blundell and Bond 1998) to estimate the empirical model. The difference GMM estimator may increase the asymptotic variance of the estimates and cause substantial bias when the endogenous variable follows a random walk, the exogenous variables are persistent over time, and the time dimension of the sample is small (Blundell and Bond 1998). This study thus employs system GMM to eliminate dynamic panel bias following Roodman (2009). The one- or two-step system GMM estimator can be used, with the two-step estimator slightly more efficient than the one-step estimator. However, when a small sample is analyzed (as in this study), the two-step GMM estimator is downward biased, whereas the one-step GMM estimator is nearly unbiased (Blundell and Bond 1998; Windmeijer 2005).

Therefore, we apply the one-step GMM estimator to test the effects of government subsidies on firms’ overinvestment. Additionally, we use a one-period lagged independent variable to address reverse causality in line with Reed (2015) and Bellemare et al. (2017). We confirm that the one-period lagged model is preferred based on the modified Akaike, Bayesian, and Hannan–Quinn information criteria, following Andrews and Lu (Andrews and Lu 2001). To produce more accurate and efficient parameter estimates, the presence of heteroscedasticity is another challenge that must be overcome. Robust standard errors (White 1980; Roodman 2009) or weighted least squares estimator (Stock and Waston 2003) can be employed to fix the existence of heteroscedasticity. We compute robust standard errors to correct the presence of heteroscedasticity.

Table 3 presents the estimation results of the dynamic panel regression. Models 1, 3, 5, and 7 estimate the effect of government subsidies on overinvestment using the different control variables. Models 2, 4, 6, and 8 estimate the influences of R&D and non-R&D subsidies on overinvestment, while controlling for different variables.

The estimation results show that external growth opportunities have a positive effect on overinvestment, that the overinvestment level in the previous period \((t - 1)\) positively affects that in the current period \((t)\), and that firm size negatively influences overinvestment at the 1% or 5% significance level. Overall, R&D nor non-R&D subsidies do not trigger overinvestment directly. Non-R&D subsidies affect overinvestment negatively by interacting with free cash flow at the 1% significance level and have a positive effect on overinvestment by interacting with leverage at the 1% or 5% level. R&D subsidies do not affect overinvestment significantly by increasing with free cash flow or leverage.

We divide sample firms into those with positive free cash flow and those with negative free cash flow. The results from models 5, 6, 7, and 8 in Table 3 indicate that firms with positive free cash flow tend to overinvest, demonstrating that \( \text{FCFPOS} \) affects \( \text{OVERIN} \) positively at the 1% significance level. The results of models 5 and 6 in Table 3 demonstrate that firms with negative free cash flow do not tend to overinvest, indicating that \( \text{FCFNEG} \) has a negative effect on \( \text{OVERIN} \) at the 1% significance level. We then test the effect of the interactions between government subsidies (R&D and non-R&D subsidies) and sources that induce overinvestment (free cash flow and leverage). The results from models 4 and 8 show that the interaction between R&D subsidies and free cash flow/leverage does not trigger overinvestment.

However, non-R&D subsidies stimulate overinvestment significantly (at the 5% level) by interacting with leverage. They also reduce a firm’s propensity to overinvest significantly.
Table 3 Dynamic panel regression analyses

Independent variable | Dependent variable = OVERIN$_{it}$
--- | ---

| Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|--- | --- | --- | --- | --- | --- | --- | --- |
| OVERIN$_{it-1}$ | 0.069 [0.040]** | 0.068 [0.040]** | 0.062 [0.038]* | 0.062 [0.038]* | 0.077 [0.036]** | 0.077 [0.036]** | 0.069 [0.036]** | 0.069 [0.036]** |
| GOVS$_{it-1}$ | 0.002 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] |
| RDS$_{it-1}$ | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.001] |
| NRDS$_{it-1}$ | 0.015 [0.008] | 0.016 [0.008]* | 0.018 [0.009]** | 0.019 [0.009]** | 0.018 [0.009]** | 0.019 [0.009]** | 0.018 [0.009]** | 0.019 [0.009]** |
| FCF$_{it-1}$ | 0.002 [0.023] | 0.001 [0.023] | −0.001 [0.018] | −0.002 [0.017] | −0.006 [0.020] | −0.005 [0.019] | −0.004 [0.019] | 0.002 [0.018] |
| FCFPOS$_{it-1}$ | −0.170 [0.020]*** | −0.169 [0.020]*** | −0.177 [0.018]*** | −0.175 [0.018]*** | −0.187 [0.017]*** | −0.186 [0.006]*** | −0.188 [0.018]*** | −0.187 [0.018]*** |
| FCFNEG$_{it-1}$ | −0.005 [0.005] | −0.005 [0.005] | −0.003 [0.005] | −0.004 [0.005] | −0.005 [0.006] | −0.005 [0.005] | −0.004 [0.006] | −0.005 [0.006] |
| FCF$_{it-1}$ | 0.031 [0.014]** | 0.034 [0.014]** | 0.033 [0.014]** | 0.036 [0.006]** | 0.038 [0.015]** | 0.040 [0.015]** | 0.036 [0.015]** | 0.041 [0.015]** |
| FCFPOS$_{it-1}$ | −0.004 [0.001]*** | −0.002 [0.000] | −0.003 [0.001] | −0.004 [0.001] | −0.005 [0.001] | −0.005 [0.001] | −0.005 [0.001] | −0.005 [0.001] |
| GOVS × FCF$_{it-1}$ | 0.001 [0.000]*** | 0.000 [0.000] | 0.000 [0.000] | 0.000 [0.000] | 0.000 [0.000] | 0.000 [0.000] | 0.000 [0.000] | 0.000 [0.000] |
| RDS × FCF$_{it-1}$ | −0.003 [0.001]*** | −0.002 [0.001] | −0.002 [0.001] | −0.002 [0.001] | −0.002 [0.001] | −0.002 [0.001] | −0.002 [0.001] | −0.002 [0.001] |
| NRDS × FCF$_{it-1}$ | −0.003 [0.001]*** | −0.003 [0.001]*** | −0.003 [0.001]*** | −0.003 [0.001]*** | −0.003 [0.001]*** | −0.003 [0.001]*** | −0.003 [0.001]*** | −0.003 [0.001]*** |
| Instruments | GMM-sys | GMM-sys | GMM-sys | GMM-sys | GMM-sys | GMM-sys | GMM-sys | GMM-sys |
| Wald($\chi^2$) | 1903.29*** | 1844.40*** | 1430.83*** | 1808.45*** | 2021.44*** | 2079.89*** | 2472.84*** | 3032.98*** |
| Sargan($\chi^2$) | 482.175*** | 483.765*** | 446.144*** | 452.608*** | 481.558*** | 482.630*** | 440.487*** | 482.686*** |
| m$_1$ (N(0, 1)) | −4.949*** | −4.962*** | −4.940*** | −4.945*** | −4.939*** | −4.951*** | −4.982*** | −4.998*** |
| m$_2$ (N(0, 1)) | 0.651 | 0.578 | 0.431 | 0.361 | 0.552 | 0.469 | 0.441 | 0.376 |
| Year dummy | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 951 | 951 | 951 | 951 | 951 | 951 | 951 | 951 |

The Sargan test is a test of overidentifying restrictions; $m_1$ and $m_2$ are tests for first-order (the null hypothesis is no first-order autocorrelation) and second-order (the null hypothesis is second-order autocorrelation) autocorrelation of the residuals, respectively. Robust standard errors are in brackets.

***1% significance; **5% significance; *10% significance
at the 1% level by interacting with free cash flow. The results are similar to those of models 3 and 7 to some extent, thereby showing the effect of the interactions between total government subsidies, free cash flow, and leverage. The two models reveal a significantly positive signal in the influence of the interaction between total government subsidies and leverage on overinvestment at the 1% significance level. In model 3, total government subsidies negatively affect overinvestment by interacting with free cash flow at the 1% significance level but are insignificant in model 7.

Discussion and conclusions

This study empirically investigated whether government subsidies influence firms’ overinvestment in the RET sector in Korea by examining the interactions between R&D and non-R&D subsidies, leverage, and free cash flow. We used unbalanced panel data from 61 RET firms in Korea between 1991 and 2018. We performed various analyses to check the data characteristics before building the empirical model and tested the nexus between the variables of interest using the one-step system GMM estimator.

This study finds that Korean firms in the RET sector tend to overinvest slightly. The RET industry is one of the most crucial drivers of environmentally sound and sustainable development in society, which requires optimal firm investment decisions (Wallsten 2000; Zhang et al. (2016)). When firms overinvest, they experience growth without increased profitability when financial conditions deteriorate, which could hinder sustainable growth by increasing dependence on external financing. Without promoting the RET sector, which requires optimal investment from RET firms, attaining environmentally sound and sustainable development may be problematic. Additionally, considering the dynamic path in overinvestment (referring to firms overinvesting in the present to some extent for the future), this need is more urgent. This phenomenon suggests that the government should proactively authorize institutions to prevent RET firms from overinvesting as well as formulate policy instruments to induce innovation, seize business opportunities, and improve productivity and profitability.

This study also shows that neither R&D subsidies nor non-R&D subsidies directly affect overinvestment alone. We find that non-R&D subsidies affect overinvestment positively by interacting with firm leverage; however, leverage does not induce overinvestment directly. Furthermore, non-R&D subsidies affect overinvestment negatively by interacting with free cash flow; however, firms with positive free cash flow tend to overinvest. It is essential that firms adjust their allocation and investment of resources to manage free cash flow efficiently based on rational criteria such as financial structure, interest rates, and prospects for profitability.

The government should also address excess liquidity through an effective tax policy. The positive effect of the interaction between non-R&D subsidies and leverage and the non-significant effect of leverage on overinvestment also suggest that although non-R&D subsidies do not trigger overinvestment directly, compared with R&D subsidies, the subsidies can more explicitly signal the certified business potential of beneficiary firms to their external investors. This is because, in Korea, non-R&D subsidies are used to purchase or modernize tangible and visible machinery and equipment to promote technological development. Non-R&D subsidies can signal a reduction in uncertainty related to firms by offering a positive sign about signal and creditworthiness of beneficiary firms and reducing information asymmetries. Such certification effect of public subsidies leads to a lower cost of debt (Lim et al. 2017) and increases the likelihood of raising long-term debt (Meuleman and Maeseneire 2012). In this process, the beneficiary firms can borrow too much beyond their optimal investment levels. Overinvestment may lead to overcapacity, which would harm the sector by lowering prices and marginal revenue. This explains why the government should implement non-R&D subsidies discretely in the RET sector. Furthermore, policy instruments that induce sound investments in machinery and equipment for RET firms are required. The government should also work towards authorizing precautionary policy measures to review the adverse reactions triggered by non-R&D subsidies.

The study confirms external growth opportunities as a factor that prompts RET firms in Korea to overinvest by demonstrating that EGO has a positive effect on OVERIN. This finding shows that overinvestment in the RET sector is induced by industry growth. In general, firms respond to economic pressure actively and seek benefits. Sales in Korea’s RET sector increased at an average annual rate of 9.5% from 1991 to 2018 (see Table 4). When industries expand rapidly, firms compete for market opportunities (Oliver 1997). Delmas and Toffel (2004) and Hanel and St-Pierre (2002) argue that the economic benefit-seeking behavior of firms in fast-growing industries is quickly imitated or adopted by competitors and that such high mimetic pressure forces RET firms to invest more strategically to stay ahead of the competition. Appropriate inter-firm competition to seize market opportunities is thus important for the development of the RET sector. Nonetheless, when competition between firms in the same industry is fierce, their profit margins decrease (Melitz 2003). This means that as inter-firm competition increases, managers are exposed to high bankruptcy, competition, and business risks, which can make firms overinvest to avoid risks and survive (LaPorta et al. 2000). Such excessive investments can diminish firm productivity and profitability even more rapidly. As such, low-productivity firms can be forced to exit the industry. This study’s results suggest that firms should respond to external opportunities.
prudently and invest based on the sound consideration of the productivity and profitability levels suited to their internal and external circumstances. The result of this study reveals that \( FS \) has a negative effect on \( OVERIN \) at the 1% significance level. This means that firm size plays a crucial role in mitigating overinvestment. As firm size increases, closer scrutiny from analysts and the investment community is enhanced (Bhushan 1989), and firms’ detailed information is more easily disclosed (Lang and Lundholm 1996). Such governance mechanisms help firms to reduce the agency problem (Mehmood et al. 2019; Nguyen et al. 2020).

| Firm group       | Sol | Geo | Sol/Geo | Sol/Win | Sol/Geo/Win | Win/Geo | Bio | Sol/Geo/Win/Bio |
|------------------|-----|-----|---------|---------|-------------|---------|-----|-----------------|
| No. of firms     | 31  | 7   | 7       | 1       | 5           | 1       | 3   | 6               |
| No. of observations (count) | 515 | 109 | 112 | 18 | 102 | 16 | 36 | 106 |
| Overinvestment (level) | 0.02 | 0.13 | 0.18 | 0.22 | 0.30 | 0.17 | 0.28 | 0.19 |
| Optimal investment (level) | 0.24 | 0.06 | 0.21 | 0.11 | 0.25 | 0.33 | 0.22 | 0.34 |
| R&D subsidies (billion KRW) | 0.273 | 0.172 | 0.597 | 0.559 | 0.162 | 0.001 | 0.001 | 0.767 |
| Non-R&D subsidies (billion KRW) | 0.551 | 0.293 | 0.708 | 0.009 | 0.128 | 0.537 | 0.005 | 0.592 |
| Free cash flow (billion KRW) | 0.210 | 0.169 | 0.133 | 0.251 | 0.214 | 0.216 | 0.213 | 0.267 |
| Leverage (percent) | 56.47 | 59.75 | 52.68 | 51.34 | 54.68 | 54.34 | 61.39 | 56.30 |
| Tangible assets (billion KRW) | 1.540 | 1.085 | 0.859 | 1.935 | 0.779 | 0.703 | 0.427 | 1.943 |
| Three-year average industry growth (rate) | 8.97 | 10.20 | 7.08 | 13.46 | 7.17 | 6.21 | 14.52 | 8.34 |
| Annual sales growth (rate) | 6.81 | 37.60 | 25.35 | 0.01 | 4.17 | 0.01 | 12.14 | 18.88 |
| No. of employees (person) | 157 | 31.4 | 59.8 | 47 | 318.0 | 201 | 88.3 | 113.6 |
| Age (year) | 22.09 | 20.28 | 20.85 | 7 | 28.8 | 35 | 16.6 | 20.5 |
| Total assets (billion KRW) | 104.973 | 107.377 | 277.107 | 21.595 | 135.571 | 26.280 | 26.981 | 86.177 |
| Annual sustainable growth (rate) | 13.86 | 10.17 | 16.81 | 26.86 | 8.35 | 3.84 | 14.67 | 11.93 |

The values in the table are the average for each firm group for 1991–2018, except for the number of firms, tangible assets, number of employees, age, and total assets, which are the average of the values of the last year: 2015, 2016, 2017, or 2018. Overinvestment refers to the overinvestment level of each firm measured as the actual investment minus the optimal investment, obtained from estimating Ding et al.’s (2019) investment equation. Annual sustainable growth rates are calculated based on Higgins’s (2009) equation. Sol, Geo, Sol/Geo, Sol/Win, Sol/Geo/Win, Win/Geo, Bio, and Sol/Geo/Win/Bio represent firm groups that engage in solar; geothermal; solar and geothermal; solar and wind; solar, geothermal, and wind; wind and geothermal; bio; and solar, geothermal, wind, and bio energy technologies, respectively.
controlling the cleft between managers and shareholders (Sehrawat et al. 2019). From the perspective of the agency theory, the result highlights the importance of the quality of information for firms that are beneficiaries of public subsidies in inducing efficient investments. This study suffers from limitations that require caution in interpreting the results. The firms in the study are located in Korea, and thus, the results cannot be generalized to other countries. This calls for further research on how government subsidies affect RET firms’ investment decisions in different countries. Furthermore, our empirical investigation focuses on the aggregate rather than the subsector level. Given the differences in firms and subsectors, the effects of government subsidies on firms’ investment decisions are likely to vary across RET subsectors. This could also be addressed in future research. This study estimates firms’ optimal investment levels following the approach of Ding et al. (2019) in which government subsidies and investment risks are not reflected. According to Nagy et al. (2021), firms’ optimal investment decisions can be different, depending on the availability, size, and withdrawal of public subsidies. Various risks, such as market (i.e., equity price, interest rate, and commodity price risks), liquidity, manager, and regulatory risks, affect firms’ optimal investment decisions. Except for the size of public subsidies that firms receive, the estimation of firms’ optimal investment levels in this study is conducted without considering public subsidy- and investment risk–related factors due to the unavailability of subsidy-related data (availability and withdrawal risks of public subsidies) and various investment risk data. On average, when the size of public subsidies is considered, the optimal investment level (0.232) is a little bit higher than when the size of public subsidies is not considered (0.224). The results of the dynamic panel regression analyses of the effects of public subsidies on firms’ overinvestment reveal that although there are differences in the magnitudes of the coefficients, the signs are similar to those of the main results reported in Table 3 (for the estimation results with the size of public subsidies, see Table 5 in Appendix). To more accurately grasp the public subsidy-investment nexus and strengthen policymakers’ ability to implement RET policy strategies more efficiently and effectively to contribute to the achievement of environmentally sound and sustainable development, future research should address the factors that may affect firms’ optimal investment decisions. The data used to test the relationship between public subsidies and firm-level overinvestment in this study are up to 2018. RET firms’ investment levels and patterns may change because of a crisis, the COVID-19 pandemic, and the enhancement of international efforts for combating climate change. This can also be addressed in future research.
## Appendix

### Table 5  Dynamic panel regression analyses with the dependent variable that considers the size of subsidies

| Independent variable | Dependent variable = OVERIN<sub>i,t</sub> | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|----------------------|------------------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|
| OVERIN<sub>i,t-1</sub> | 0.058 [0.046]** | 0.052 [0.045]** | 0.052 [0.045]** | 0.051 [0.044]** | 0.058 [0.046]** | 0.056 [0.045]** | 0.058 [0.047]** | 0.057 [0.046]** |
| GOVS<sub>i,t-1</sub> | 0.004 [0.001] | 0.002 [0.001] | 0.002 [0.001] | 0.004 [0.001] | 0.004 [0.001] | 0.003 [0.001] | 0.003 [0.001] | 0.003 [0.009] |
| RDS<sub>i,t-1</sub> | 0.002 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.002 [0.001] | 0.002 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.010 [0.011] |
| NRDS<sub>i,t-1</sub> | FCF<sub>i,t-1</sub> | 0.008 [0.012] | 0.008 [0.012] | 0.007 [0.013] | 0.005 [0.013] | 0.002 [0.001] | 0.001 [0.001] | 0.001 [0.001] | 0.001 [0.009] |
| LEV<sub>i,t-1</sub> | 0.029 [0.036] | 0.032 [0.035] | 0.027 [0.034] | 0.033 [0.034] | 0.029 [0.036] | 0.033 [0.035] | 0.029 [0.041] | 0.041 [0.039] |
| FS<sub>i,t-1</sub> | −0.129 [0.025]** | −0.129 [0.025]** | −0.135 [0.024]** | −0.134 [0.024]** | −0.128 [0.024]** | −0.128 [0.024]** | −0.131 [0.023]** | −0.130 [0.023]** |
| IGO<sub>i,t-1</sub> | −0.002 [0.005] | −0.002 [0.005] | −0.002 [0.005] | −0.002 [0.005] | −0.001 [0.005] | −0.001 [0.005] | −0.001 [0.005] | −0.001 [0.005] |
| EGO<sub>i,t-1</sub> | 0.029 [0.005]** | 0.031 [0.017]** | 0.032 [0.017]** | 0.052 [0.007]** | 0.027 [0.017]** | 0.030 [0.018]** | 0.028 [0.018]** | 0.030 [0.007]** |
| FCFPOS<sub>i,t-1</sub> | 0.003 [0.023] | 0.001 [0.024] | 0.003 [0.023] | 0.001 [0.023] | 0.003 [0.023] | 0.001 [0.023] | 0.003 [0.023] | 0.000 [0.007] |
| FCFNEG<sub>i,t-1</sub> | −0.016 [0.028] | −0.016 [0.028] | −0.016 [0.028] | −0.016 [0.028] | −0.009 [0.029] | −0.009 [0.029] | −0.009 [0.029] | −0.013 [0.030] |
| GOVS × FCF<sub>i,t-1</sub> | 0.001 [0.001]** | −0.003 [0.001]** | −0.003 [0.001]** | −0.003 [0.001]** | 0.001 [0.001]** | 0.001 [0.001]** | 0.001 [0.001]** | 0.001 [0.001]** |
| GOVS × LEV<sub>i,t-1</sub> | 0.001 [0.001]** | −0.003 [0.001]** | −0.003 [0.001]** | −0.003 [0.001]** | 0.001 [0.001]** | 0.001 [0.001]** | 0.001 [0.001]** | 0.001 [0.001]** |
| RDS × FCF<sub>i,t-1</sub> | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** |
| RDS × LEV<sub>i,t-1</sub> | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** |
| NRDS × FCF<sub>i,t-1</sub> | 0.003 [0.001] | 0.003 [0.001] | 0.003 [0.001] | 0.003 [0.001] | 0.003 [0.001] | 0.003 [0.001] | 0.003 [0.001] | 0.003 [0.001] |
| NRDS × LEV<sub>i,t-1</sub> | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** | 0.001 [0.000]** |

The Sargan test is a test of overidentifying restrictions; m<sub>1</sub> and m<sub>2</sub> are tests for first-order (the null hypothesis is no first-order autocorrelation) and second-order (the null hypothesis is second-order autocorrelation) autocorrelation of the residuals, respectively. Robust standard errors are in brackets.

**1% significance; **5% significance; *10% significance
Author contribution B. Sung and S.D. Park conceived and designed the research idea. B. Sung analyzed the final model. B. Sung, MC. Choi, and S.D. Park proposed implications based on the results of this paper. All the authors have read and approved the final manuscript.

Funding This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2019S1A5A2A01038562).

Data availability The datasets are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Ahn S, Denis DJ, Denis DK (2006) Leverage and investment in diversified firms. J Financ Econ 79:317–337
Aivazian V, Ge Y, Qiu J (2005) The impact of leverage on firm investment: Canadian evidence. J Corp Financ 11:277–291
Akerlof GA (1970) The market for ‘Lemons’: quality, uncertainty, and the market mechanism. J Q Econ 84:488–500
Andonova A, Ruiz-Pava R (2016) The role of industry factors and intangible assets in company performance in Colombia. J Bus Res 69:4377–4384
Andrews DWK, Lu B (2001) Consistent model and moment selection procedures for GMM estimation with application to dynamic panel data models. J Econometrics 101:123–164
Ang G, Rottgers D, Burli P (2017) The empirics of enabling investment and innovation in renewable energy. Environment Working Papers No. 123, OECD, Paris
Arellano M, Bond S (1991) Some tests of specification for panel data models. J Econometrics 48:21–52
Arellano M, Bond S (1991) The incidence of structural equations in the educational technology of Iran. Variables of intellectual capital and its dimensions with the approach of structural equations in the educational technology of Iran. Eurasia J Math Sci Technol Educ 14:1663–1682
Banerjee AV (1992) A simple model of herd behavior. Q J Econ 107:415–442
Bates TW (2005) Asset sales, investment opportunities, and the use of proceeds. J Financ 60:105–135
Bellemare MF, Pepinsky TB, Masaki T (2017) Lagged explanatory variables and the estimation of causal effects. J Politi 79:949–963
Blundell R, Bond S (1998) Initial conditions and moment restrictions in dynamic panel data models. J Econometrics 87:115–143
Brown RL, Durbin J, Evans JM (1975) Technologies for testing the constancy of regression relationships over time. J R Stat so Series B (methodological) 37:149–192
Bürer MJ, Wüstenhagen R (2009) Which renewable energy policy is a venture capitalist’s best friend? Empirical evidence from a survey of international cleantech investors. Energy Policy 37:4997–5006
Busom I, Fernandez-Ribas A (2008) The impact of firm participation in R&D programmes on R&D partnerships. Res Policy 37:240–257
Cerulli G, Gabriele R, Poti B (2016) The role of firm R&D effort and collaboration as mediating drivers of innovation policy effectiveness. Ind Innov 23:426–447
Chang K, Zeng Y, Wang W, Wu X (2019) The effects of credit policy and financial constraints on tangible and research and development investment: firm level evidence from China’s renewable energy industry. Energ Policy 130:438–447
Clarysse B, Wright M, Mustar P (2009) Behavioral additionality of R&D subsidies: a learning perspective. Res Policy 38:1517–1533
Corsatea TD, Giaccaria S, Arântegui RL (2014) The role of sources of finance on the development of wind technology. Renew Energ 66:140–149
Costa R (2012) Assessing intellectual capital efficiency and productivity: an application to the Italian yacht manufacturing sector. Expert Syst Appl 39:7255–7261
Crespi G, Maffioli A, Rastelletti A (2014) Investing in ideas: politics to foster innovation. In: Fernandez-Arias E, Crespi G, Stein E (eds) Rethinking productive development: sound policies and institutions for economic transformation. Palgrave Macmillan, New York, 014, pp. 61–106
Czarnitzki D (2006) Research and development in small and medium-sized enterprises: the role of financial constraints and public funding. Scat J Polit Econ 53:335–357
D’Mello R, Miranda M (2010) Long-term debt and overinvestment agency problem. J Bank Financ 34:324–335
Dechellepré A, Martin R, Mohren M (2017) Knowledge spillovers from clean and dirty technologies: a patent citation analysis. Grantham Research Institute, London, UK
Delmas M, Toffel MW (2004) Stakeholders and environmental management practices: an institutional framework. Bus Strateg Environ 13:209–222
DiMaggio PJ, Powell WW (1991) The iron cage revisited: institutional isomorphism and collective rationality in organizational field. In: Powell WW, DiMaggio PJ (eds) The new institutionalism in organizational analysis. University of Chicago Press, Chicago, pp 63–82
Dimos C, Pugh G (2016) The effectiveness R&D subsidies: a meta-regression analysis of the evaluation literature. Res Policy 45:797–815
Ding S, Knight J, Zhang X (2019) Does China overinvest? Evidence from a panel of Chinese firms. Eur J Financ 25:489–507
Faulkender M, Wang R (2006) Corporate financial policy and the value of cash. J Financ 61:1957–1990
Feldman MP, Kelley MR (2006) The ex-ante assessment of knowledge spillovers: government R&D policy, economic incentives and private firm behavior. Res Policy 35:1509–1521
Foxxon TJ, Gross R, Chase A, Howes J, Arnall A, Anderson D (2005) UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energ Policy 33:2123–2137
Garrone P, Piscitelto L, Wang Y (2014) Innovation performance and international knowledge spillovers: evidence from the renewable energy sector in OECD countries. Ind Innov 21:574–598
Gillingham K, Sweeney J (2010) Market failure and the structure of externalities. In: Padilla A, Schmalensee R (eds) Harnessing renewable energy in electric power systems, Earthscan LLC, London, UK, pp. 69–91

 Springer
Hall BH (2002) The financing of research development. Oxford Rev Econ Pol 18:35–51
Hanel P, St-Pierre A (2002) Effects of R&D spillover and the profitability of firms. Rev Ind Organ 20:305–322
Hendershott R (1996) Which takeover targets overinvest? J Financ Quant Anal 31:563–580
Higgins RC (2009) Analysis for financial management. McGraw Hill, New York
Hopmann J (2018) The role of interfirm knowledge spillovers for innovation in mass-produced environmental technologies: evidence from the sola photovoltaic industry. Organ Environ 31:1–24
Hörte S-Å (2004) Knowledge spillover aspects of cooperation and competition. In: Karlsson C, Flensburg P, Hörte S-Å (eds) Knowledge spillovers and knowledge management, Doward Elgar, Cheltenham, UK, pp. 94–109
Jacobsson S, Karlorp K (2013) Mechanisms blocking the dynamics of the European offshore wind energy innovation system – challenges for policy intervention. Energ Policy 63:1182–1195
Jalonen H (2012) The uncertainty of innovation: a systematic review of the literature. J Manage Res 4:1–47
Jensen MC (1986) Agency costs of free cash flow, corporate finance, and takeovers. Am Econ Rev 76:323–329
Jensen MC, Meckling WH (1976) Theory of the firm: managerial behaviour, agency cost and ownership structure. J Financ Econ 3:305–369
Karpavičius A, Yu F (2019) External growth opportunities and a firm’s financing policy. Int Rev Econ Financ 62:287–308
Kennedy PA (1992) Guide to econometrics. Blackwell, Oxford, UK
Kim T, Lee D-J, Koo S (2014) Determining the scale of R&D investment for renewable energy in Korea using a comparative analogy approach. Renew Sust Energ Rev 37:307–317
Koetsier R, Bikker JB (2018) Herding behaviour of Dutch pension funds in asset class investment. Discussion Paper Series 18–04. Utrecht University School of Economics, Tjalling C. Koopmans Institute
Koseoglu NM, Van Den Bergh JCJM, Lacerda JS (2013) Allocating subsidies to R&D or to market applications of renewable energies? Balance and geographical relevance. Energy Sustain Dev 17:536–545
Lang MH, Lundholm RJ (1996) Corporate disclosure policy and analyst behaviour. Account Rev 71:253–274
Laporta R, Lopez-de-Silanes F, Shleifer A, Vishny R (2000) Agency problem and dividend policy around the world. J Financ 55:1–33
Leland HE, David HP (1977) Informational asymmetries, financial structure, and financial intermediation. J Financ 32:317–387
Lim CY, Wang J, Zeng C (2017) China’s “mercantilist” government subsidies, the cost of debt and firm performance. J Bank Financ 86:37–52
Linores P, Labanderia X (2013) Renewable electricity support in Spain: a natural policy experiment. Economics of Energy Working Paper, WP 04/2013, Economics for Energy, Madrid, Spain
Liu D, Chen T, Liu X, Yu Y (2019) Do more subsidies promote greater innovation? Evidence from the Chinese electronic manufacturing industry. Econ Model 80:441–452
Liu W, Xu X, Yang Z, Zhao J, Xing J (2016) Impacts of FDI renewable energy technology spillover on China’s energy industry performance. Sustainability 8:846
López-de-Oronda O, López-de-Silanes F, López-Iiturriaga FJ, Stan-tamaria-Mariscal M (2019) Overinvestment, leverage and financial system liquidity: a challenging approach. BRQ-Bus Res Q 22:96–104
Lu W-M, Wang W-K, Tung W-T, Lin F (2010) Capability and efficiency of intellectual capital: the case of fabless companies in Taiwan. Expert Syst Appl 37:546–555
Luding S, Schmid E, Haller M, Bauer N (2015) Assessment of transformation strategies for the German power sector under the uncertainty of demand development and technology availability. Renew Sust Energ Rev 46:143–156
Mazzucato M, Semieniuk G (2018) Financing renewable energy: who is financing what and why it matters. Technol Forecast Soc 127:8–22
McNichols M, Stubben S (2008) Does earnings management affect firms’ investment decisions? Account Rev 83:1571–1603
Mehmood R, Hunjra AI, Chani M (2019) The impact of corporate diversification and financial structure on firm performance: evidence from South Asian countries. J Risk Finance 12:49
Meijer ISM, Hekkert MP, Koppenjan JFM (2007) The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technologies: biomass gasification projects in the Netherlands. Energ Policy 35:5836–5854
Meleddu M, Pulina M (2018) Public spending on renewable energy in Italian regions. Renew Energ 115:1086–1098
Melitz MJ (2003) The impact of trade on intra-industry reallocations and aggregate industry productivity. Econometrica 71:1695–1725
Merli M, Roger T (2013) What drives the herding behaviour of individual investors? Finance 34:67–104
Meuleman M, De Maeseneire W (2012) Do R&D subsidies affect SMEs’ access to external financing? Res Policy 41:580–591
Myers S (1977) Determinants of corporate borrowing. J Financ Econ 5:147–175
Myers S, Majluf M (1984) Corporate financing and investment decisions when firms have information that investors do not have. J Financ Econ 13:187–221
Nagy RLG, Hagspiel V, Kort PM (2021) Green capacity investment under subsidy withdrawal risk. Energ Econ 98:105259
Nguyen AH, Doan DT, Nguyen LH (2020) Corporate governance and agency cost: Empirical evidence from Vietnam. J Risk Finance 13:103
OECD (2013) OECD policy guidance for investment in clean energy infrastructure: Expanding access to clean energy for green growth and development. OECD, Paris
Oliver C (1997) The influence of institutional and task environment relationships on organizational performance: the Canadian construction industry. J Manag Stud 34:99–124
Peneder M (2008) The problem of private under-investment in innovation: a policy mind map. Technovation 28:518–530
Pesaran MH (2004) General diagnostic tests for cross section dependence. J Appl Econ 9:435, University of Cambridge, Cambridge, UK
Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Econ 22:96–104
Pesaran MH (2008) Cross-section dependence for a linear dynamic panel model with regressors. J Econometrics 148:149–161
Polzin F, Migendt M, Täube F (2015) Public policy influence on renewable energy investment—a panel data study across OECD countries. Energ Policy 80:98–111
Reed WR (2015) On the practice of lagging variables to avoid simultaneity. Oxford B Econ Stat 77:897–905
Roodman D (2009) How to extabond2: an introduction to difference and system GMM in Stata. Stata J 9:86–136
Roos J, Roos G, Edvinsson L, Dragonetti NC (1997) Intellectual capital: navigating in the new business landscape. Macmillan, New York
Rout UK, Blesl M, Fahl U, Remme U, Vos A (2009) Uncertainty in the learning rates of energy technologies: an experiment in a global multi-regional energy system model. Energ Policy 37:4927–4942
Sarafidis V, Yamagata T, Robertson D (2009) A test for cross section dependence for a linear dynamic panel model with regressors. J Econometrics 148:149–161
