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Green innovation and firm performance: Evidence from listed companies in China

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ABSTRACT

This paper focuses on how green patenting influences a firm's subsequent performance. By investigating listed manufacturing firms in China for the 2000–2010 period, we find a positive and significant relationship between green patenting and firm performance. Moreover, our research reveals that green growth is mainly driven by green utility-model patents and that this positive relationship only exists among state-owned enterprises (SOEs), which are more capable of leveraging green innovation through their close relationship with the government. Furthermore, the positive relationship is found to exist primarily after 2006, when the government began to provide formal legislative support to green industry.

1. Introduction

Green innovation has become a popular concept in recent years as global warming and environmental deterioration continue to pose serious threats to the world population (Kunapatarawong and Martínez-Ros, 2016; Miao et al., 2017). Sustainability is a crucial concern, and calls for green growth have been ever more urgent. There is no doubt that technological progress is one of the most important forces enabling green development; however, innovation is costly in general. Therefore, the key issue is whether green innovation can improve growth while maintaining its environmental benefits.

While China has experienced unprecedented economic growth in the forty years since its economic reform and opening-up policies, sustainability has only become a real concern in recent years (Fang and Wen, 2012; Cui and Huang, 2018; Cui et al., 2018; Chams and García-Blandón, 2019; Orzes and Sarkis, 2019). The economic advances have relied heavily on energy consumption—mainly fossil fuel energy (Ji and Zhang, 2019; Ji et al., 2019); consequently, environmental problems have become ever more threatening. In response to the increasing pressure from both sides of this issue, the Chinese government set up clear strategic targets to prompt green development. For example, in the recent 13th Five-Year Plan (FYP), green development and technological energy innovation have become fundamental principles for the future (Song et al., 2017).

Although nations worldwide have signed off on a general agreement to move towards a green growth track (i.e., the Paris Agreement), it remains very important to ensure that the objective is incentive-compatible with individual firms, which are essentially the building blocks of green innovation and growth. Stucki (2018), for example, argues that firms will only invest in green technologies if they are profitable. The question is whether environmentally friendly technology investments can boost firm performance. Negative views, such as those expressed by Palmer et al. (1995), suggest that firms engaging in green innovation could be inefficient and suffer productivity losses. Huang and Li (2017), on the contrary, find that green innovation can improve performance. Fernando et al. (2019) suggest that eco-innovation can improve service innovation and lead to better business performance. The findings related to this question are still inconclusive (Tang et al., 2018) and sensitive to the choice of samples, the method of analysis, and the empirical design.

This paper aims to contribute to the general innovation and growth literature by focusing on firm-level evidence with further extension to green innovation. While the relationship between general innovation and growth has been well documented (e.g. Grossman and Helpman, 1994), it is shown that entrepreneurial activity is the foundation of national economic growth (van Stel et al., 2005), in addition, Segerstrom (1991) develops a model showing that firms' innovation can promote economic growth. The question can be extended to green/

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sustainable innovations (Boons et al., 2013) and according to what we have mentioned above, it is not quite clear how green innovation of firms may contribute to sustainable economic growth.

We join the debate discussed above by providing further empirical evidence on the question of whether green innovation can enhance firms' growth and improve their performance. Specifically, we investigate this issue using data from China, the largest developing country and the largest emitter of greenhouse gases in the world. Meanwhile, China is also the largest investor in the renewable energy sector in the world (Zhang et al., 2016b). There are also clear policies and regulatory support for green innovation in this country.

Chen et al. (2018), for example, argue that institutional pressures lead to corporate green innovation, based on Chinese firm-level data. Long et al. (2017) find that environmental innovations are more effective for improving environmental performance relative to the economic performance of firms. Guo et al. (2018), Yuan and Xiang (2018), among others, also emphasize the importance of green growth and link innovation and green development in Chinese manufacturing firms. Clearly, certain issues remain, especially at the firm level. It is therefore of great interest to examine the innovation-performance relationship of Chinese firms, with a special focus on the role of green patents.

Listed firms in the manufacturing industry are used for this empirical study. R&D expenditures and patents are typical proxies for innovation input and output (e.g., Cruz-Cázares et al., 2013). They have, however, apparent shortcomings. For example, simple counts of patents fail to address the heterogeneity of quality across patents. One of the major contributions of our paper is the use of citation-weighted patent counts as the key variable for innovation output, which can accommodate the heterogeneity of patent quality. Given the potential lagged effects of green innovation, the empirical regressions in this paper allow for lags of up to three years. We measure firm performance using two variables: sales growth and net profits.

Our estimation results show that there is a positive and significant relationship between green patents and firm performance. Moreover, the effect is mainly driven by green utility-model patents. We further identify two possible mechanisms through which green utility-model patents stimulate firms' performance: state ownership and regulation enforcement. We find that a positive relationship mainly exists among SOEs, which are supposed to be more capable of leveraging green innovation through their close relationship with governments. In 2006, China passed the Renewable Energy Law (REL), which provides legal support for the development of green energy and also demonstrates the government's determination to pursue a green development track. Our empirical evidence also demonstrates that the positive green innovation-performance relationship is found primarily after 2006, indicating that the regulatory or institutional environment plays an important role.

The remainder of this paper is structured as follows. Section 2 reviews relevant literature aiming to build up the foundation of this research, where a number of testable hypotheses have been developed in Section 3. Section 4 describes the data and key variables. Section 5 reports the main empirical results, and the last section concludes.

2. Literature review

2.1. Green innovation and growth

Energy, such as crude oil and coal, has long been considered one of the most important ingredients of economic growth (Stern and Cleveland, 2004; Ji and Zhang, 2018; Song et al., 2018a,b). Growth backed by fossil fuels, however, has obvious drawbacks because they are not only exhaustible but also undesirable by-products (e.g., carbon dioxide). These problems have led to a trend towards sustainability in international society. Technological innovation, which improves efficiency, introduces the clean use of resources, or discovers renewable energy sources, is an obvious solution to achieve sustainable growth. The importance of green innovation and related relevant issues are therefore attracting growing attention (Cancino et al., 2018), though the concept of green innovation remains rather loosely defined. In the literature, *eco-innovation*, *sustainable innovation*, and *environmental innovation* have often been used interchangeably, with no clear boundaries between them (Schiederig et al., 2011). The general purposes of green innovation, however it is defined, are related to technological progress with environmental benefits, which can take the form of new products or new processes that contribute to sustainability and environmental protection (Oltra and Saint Jean, 2009). In general, we do not distinguish between the subtle differences among these concepts; instead, we use green innovation to represent all relevant terms in the following part of our paper.

Although the relationship between innovation and growth has been widely discussed in the literature (i.e., Cameron, 1998; Scherer, 1986), the green innovation and sustainable growth nexus has only appeared in recent years, as is evident in the increasing attention devoted to it in the literature. Rennings (2000) looks into the conceptual issues of green innovation and emphasizes the need to develop theoretical and methodological approaches to understand innovation and sustainable development. Cancino et al. (2018) summarize 375 recently published studies on innovation and sustainable growth. Using an ontological framework, they show that there are significant gaps in the literature; for example, cultural issues have been largely neglected. Due to the availability of data, firm-level studies remain limited.

2.2. Green innovation in China

In fact, technological progress has become one of the most important driving factors for development in China. R&D investment has been increasing steadily from 461.6 billion RMB in 2008 to 1750 billion RMB in 2017[1], more than tripling in the last ten years. Investment in renewable energy in China also has experienced dramatic growth, recently overtaking the EU and the US to become the world's top investor in this area (Zhang et al., 2016b). The Renewable Energy Law was passed by the National People's Congress of China in 2005 and implemented the following year. This has provided legislative support for green development in China.

Partially due to continuous inputs in innovation, energy intensity in China has fallen substantially from over 20 t of standard coal per 10 thousand RMB real GDP in the late 1970s to less than 8 tons of standard coal per 10 thousand RMB real GDP in recent years (Zhang and Broadstock, 2016). However, energy intensity is still clearly far from the levels of developed economies (Zhang et al., 2016a) and requires further efforts. Song et al. (2015) find, however, that there are clear regional disparities in terms of the economic development-green innovation relationship in China. Further, Chen et al. (2017) prove that regional green innovation decreases gradually from east to west in China.

2.3. Green innovation and firm performance

It is clear that green innovation and green development are the way forward and they have gained strong policy supports. However, the question remains whether a general macro-level development strategy is consistent with micro-level incentives. In other words, can green innovation yield economic or financial benefits for individual firms? A recent surge of literature has started to explore this question inventively. Saunila et al. (2018) link sustainability with green innovation investment and exploitation. They find that green innovation is driven by economic and social pressures to pursue sustainable growth. Cai and Li (2018) find that both internal resources and external pressures drive firms' green innovation decisions, which further reinforce

[1] Source: National Bureau of Statistics, China

the role of market-based mechanisms in promoting green innovation. In general, they find supporting evidence for the so-called Porter Hypothesis and suggest that firms can obtain indirect improvements in economic performance from environmental performance driven by green innovation. Arfi et al. (2018) investigate a sample of small and medium-sized enterprises (SMEs) in France and suggest that the risk attendant in knowledge transfer regarding green innovation can impose negative effects on firms' performance. Jiang et al. (2018) use a sample of 264 Chinese firms to show that green entrepreneurial orientation plays a positive role in the green innovation-performance relationship. Lee and Min (2015) find a positive impact of green innovation on firm performance in Japan. Stucki (2018), however, asserts that only 19% of firms enjoy better performance with green investment, whereas green investment in the remaining 81% of firms has insignificant or even negative impacts on returns.

One of the common problems of the existing literature is how to measure green innovation properly. Klewitz and Hansen (2014) review the literature on the green innovation of SMEs and sort their innovations into three categories: process, organizational, and product innovation. García-Granero et al. (2018) find 30 indicators for eco-innovation performance based on a literature review encompassing 104 articles. They find that the top indicators are related to process innovation, which accounts for 36% in these articles, followed by organizational innovation and product innovation.

R&D is a typical measure of innovation input (Tumelero et al., 2019), although it fails to yield information on output. Patents are another popular measure of innovation. There are a number of advantages to use patent data to proxy for firms' innovation output. For example, as patent applications are examined through a consistent and rigorous process, the progress of innovation is thus well captured by patent data. Moreover, China is transforming from an economy of imitation into one of innovation (e.g., Cai and Tylecote, 2008; Guan et al., 2009).

The patent quality, however, is heterogeneous (Gambardella et al., 2008). Li (2012) documents that subsidies contributed to China's recent patenting surge, raising concerns that patent counts may overestimate the quality of invention (Dang and Motohashi, 2015). Lei et al. (2012) show that to meet annual patenting quotas, Chinese firms' patent filings exhibit a peak in December. Consequently, it is possible that when a firm is filing more patent applications, its actual invention is unchanged or even worsened. It has been shown that more citations by subsequent patents indicate a higher commercial value of the underlying invention (Jaffe and De Rassenfosse, 2017; Hall et al., 2005; Harhoff et al., 1999). As the count of forward citations is a reliable proxy for patent quality (Gambardella et al., 2008; Reitzig, 2004), we use citation-weighted patent counts as our major measure of firms' innovation output.

3. Hypotheses building

Based on the discussion of prior literature, we can formulate the following testable hypotheses:

H1. Green innovation can improve firm performance.

The Porter Hypothesis, which is proposed by Porter and van der Linde (1995), suggests that environmental regulation can encourage innovation and significantly improve competitiveness. This is the foundation in the literature to study the links between green innovation and firm performance. Based on the existing literature (e.g. those in Section 2.3) and this hypothesis, we expect that green innovation can have a positive impact on firm performance in China. High-quality green patents allow firms to experience a higher speed of growth and to gain more economic benefits.

H2. The economic benefits of green innovation are more pronounced for SOEs.

In Chinese listed firms, state shares are about one-third of the total shares. Consequently, two types of listed firms coexist: SOEs and non-SOEs. Evidence shows that in SOEs, managers have less incentive to innovate (e.g., Hu and Jefferson, 2009).

However, there is another aspect that we need to consider before we draw any conclusions. SOEs are part of China's political system, and their top managers have political rankings, which can be as high as the ministerial level. The party secretary of a listed SOE is at the top position, who also acts as the chair of the board. Consequently, listed SOEs naturally have a closer relationship with the government than non-SOEs.

Generally, environment-related projects are promoted by the government. These projects may entail various requirements, such as involving green-related technologies. Once an SOE has green patents and, thus, is qualified to compete for the projects, its close relationship with the government will substantially help it to win projects. We tend to believe that this effect will dominate other factors. Consequently, we expect that the positive relationship between green patenting and firm performance is more pronounced among SOEs.

H3. External environment has a significant impact on green patenting effects.

This hypothesis is largely rooted in previous studies such as Saunila et al. (2018) and Cai and Li (2018), which argue that external environments or regulatory pressures drive firms' green innovation. While it is easy to understand that a favourable regulatory environment can boost green innovation, whether this type of innovation can generate economic benefits for firms is not entirely clear. It is likely that if firms invest in green technology simply as a response to policies or external pressures, the associated innovation may fail to generate economic benefits (e.g., Arfi et al., 2018). On the other hand, a favourable regulatory environment can generate an advantageous market environment and increase competitiveness for firms with green technologies, which in the end yields financial benefits. In this paper, we believe that the latter effect should work for China, especially since the Chinese government passed the Renewable Energy Law. Strong legislative support not only attracts more investment (Zhang et al., 2016b) but also allows firms to exploit their competitive advantage more effectively.

4. Data

Our fundamental data on firms' financial information come from the China Stock Market and Accounting Research Database (CSMAR). Listed firms are used for the 2000–2010 sample period. The endpoint of our sample is explained by the unavailability of relevant patenting information after 2010. Given that we rely on forward citation information, which takes time to generate reliable measures (Hall et al., 2001), we believe the chosen sample size can generate reasonable results and generalizable implications. Data on Chinese listed firms are reliable and have been widely studied (e.g., Fisman and Wang, 2010; Kato and Long, 2006; Fernald and Rogers, 2002). To measure a firm's performance, at the least two dimensions should be examined, namely profitability and growth. Innovative activities may enhance both a firm's profitability and its growth. The first measure we employ, net profits, measures firms' profitability. It is widely used as a measure of profitability in innovation studies (e.g., Roberts and Amit, 2003). To capture a firm's growth, we use sales growth as our second measure.

Firms' patenting information comes from a recent database, the Chinese Patent Data Project (CPDP), constructed by He et al. (2013). The project matches patent applications at the SIPO (State Intellectual Property Office) with listed Chinese firms. Specifically, it covers all main-board A-share firms listed on both the Shanghai and Shenzhen stock exchanges. Additionally, for completeness, the CPDP database takes into account subsidiaries' patenting information. A total of 222,651 filed patent applications are included, with application years ranging from 1992 to 2010; the grant information stops at 2011. To deal with the issue that most of the patent applications submitted in

2010 and had not been granted by 2011 and may be granted at a later date, we turn to the PATSTAT to update the grant information for all patents up to 2016.

Identifying whether a patent application should be counted as green innovation is another major issue in this study. Scholars often identify green innovation by using the US patent classification system (e.g., Amore and Bennedsen, 2016). Our focus is on Chinese listed firms whose patents are classified through the International Patent Classification (IPC) in the PATSTAT. Fortunately, the EST (energy-sustainable technology) concordance table provided by the USPTO also publishes the related IPC classification. It is therefore easy to identify whether a patent is a green one based on its IPC classification.

Two measures of firms' innovation output are constructed as follows. The first one is patent counts. The SIPO grants three types of patents: invention, utility-model, and external-design patents. Invention patents have the highest novelty. To be granted as an invention patent, the requirement of "novelty, inventiveness, and practical applicability" has to be met. In contrast, for utility-model and external-design patents, it is only required that a similar application has not been granted. We only count invention and utility-model patents because external-design patents are obviously not green patents. To appropriately reflect a firm's innovation output in a given year, patents are counted based on the application year. It is also required that a patent is granted to ensure its validity. Following these principles, patents are counted for each firm-year to generate our first patenting measure, *patent counts*. According to whether a patent is classed as green innovation and whether a patent is of the invention or utility-model type, patent counts are divided into four categories, namely EST invention, EST utility, other invention, and other utility.

Our second measure is *citation counts* (i.e., citation-weighted patent counts). Following Boeing and Mueller (2016) and Rong et al. (2017), we retrieve citation information from the 2016 autumn PATSTAT and generate citation counts for each patent. Specifically, we count each patent's forward citations received up to autumn 2016. We then generate a firm-year's citation counts by computing the total number of forward citations received by patents that are applied for by the firm in the given year. Since it has been well documented that citation counts are a better measure than patent counts, we use citation counts as our major measure of innovation output in our estimations.

Given the availability of patent information, we focus on firms listed on the main board of the Shanghai and Shenzhen Stock Exchanges. To process the data, we first restrict the sample to the years 2000–2010. The CPDP database only allows us to reliably use the patenting information up to 2010. Second, based on the first digit of the industry classification, we include only manufacturing firms, which are the most green-innovation related and produce the majority of patents. Third, firms that are delisted during the sample period are excluded to avoid delisting effects. Fourth, to avoid the effects of IPOs, in which the first few years of financial reports are likely to be manipulated and thus unreliable, we also drop the firms that had an IPO within three years. Last, observations with invalid value and those with leverage ratios greater than one are also excluded. After the application of these procedures, our total effective sample ends up having 5727 observations representing 764 firms.

Table 1 presents the summary statistics for our sample. To control for outliers, all financial variables are winsorized at the 1% level in both tails. The distribution of citation counts was highly skewed, with a mean of 10.17 and a maximum of 6400. Among the 10.17 citation counts, only 0.52 counts (about 5%) came from green patents; the remaining 9.65 came from other patents, indicating that green innovation was relatively a new thing in China. There were 1006 sampled firm-years with positive citation counts, among which the average was 57.89 and the median was 10. On average, each firm-year had 10.90 patent counts, while the maximum was 3856. On average, 31% of firms' total assets were fixed assets. The annual sales growth rate was around 16%, indicating that Chinese listed firms grew rapidly during our examination period. The profitability was relatively low, at around 5%.

Table 1
Summary statistics.

	Mean	S.D.	Min.	P25	P50	P75	Max.
Sales growth, t + 2	0.14	0.33	−0.54	−0.01	0.08	0.21	1.92
Sales growth, t + 3	0.16	0.41	−0.71	−0.02	0.08	0.23	2.44
Sales growth, t + 4	0.18	0.52	−0.84	−0.03	0.07	0.24	3.23
Net profit, t + 2	0.04	0.09	−0.24	0.01	0.03	0.07	0.42
Net profit, t + 3	0.05	0.11	−0.25	0.01	0.03	0.08	0.54
Net profit, t + 4	0.06	0.14	−0.29	0.01	0.03	0.10	0.71
Citation count, t	10.17	149.84	0.00	0.00	0.00	0.00	6400.00
- EST patent	0.52	2.49	0.00	0.00	0.00	0.00	50.00
EST invention	0.38	2.05	0.00	0.00	0.00	0.00	50.00
EST utility	0.14	0.95	0.00	0.00	0.00	0.00	28.00
- Other patent	9.65	148.71	0.00	0.00	0.00	0.00	6365.00
Other invention	7.57	143.76	0.00	0.00	0.00	0.00	6233.00
Other utility	2.08	12.73	0.00	0.00	0.00	0.00	249.00
Patent count, t	10.90	97.14	0.00	0.00	0.00	0.00	3856.00
- EST patent	0.66	2.83	0.00	0.00	0.00	0.00	62.00
EST invention	0.29	1.66	0.00	0.00	0.00	0.00	62.00
EST utility	0.38	1.92	0.00	0.00	0.00	0.00	53.00
- Other patent	10.23	95.97	0.00	0.00	0.00	0.00	3838.00
Other invention	4.62	80.11	0.00	0.00	0.00	0.00	3563.00
Other utility	5.61	32.78	0.00	0.00	0.00	0.00	628.00
Ln(Total assets), t	21.46	1.06	19.16	20.76	21.40	22.09	24.65
Leverage, t	0.50	0.18	0.11	0.38	0.51	0.63	0.93
Fixed asset ratio, t	0.31	0.15	0.04	0.19	0.28	0.41	0.69
SOE dummy, t	0.64	0.48	0.00	0.00	1.00	1.00	1.00
Observations	5727						

5. Empirical results

5.1. Model setups

This section examines our testable hypotheses based on a regression framework as follows:

$$FP_{i,t+3} = a_1 Pat_{i,t} + X_{i,t} a_2 + Year\_dum + Firm\_dum + \varepsilon_{i,t}, \quad (1)$$

where the dependent variable $FP_{i,t+3}$ represents firm *i*'s performance in year $t+3$. We use $Sales\_growth_{t+3}$ (operational income in year $t+3$ minus operation income in year $t+2$ normalized by total assets in year *t*) and Net_profit_{t+3} (net profit in year $t+3$ normalized by total assets in year *t*) to measure firm performance in year $t+3$, respectively.

The variable of interest $Pat_{i,t}$ represents firm *i*'s patent output in year *t*, which is also normalized by total assets in year *t*. Following the literature, $X_{i,t}$ represents a vector of firm characteristics that may influence firm *i*'s subsequent performance. It includes log of total assets, leverage ratio, and fixed-asset ratio. Note that firm performance is forwarded by three years to patent output. This setting is consistent with the finding by Ernst (2001) that patents have a lag of two to three years in their effect on sales. $Year\_dum$ represents a vector of year dummies to account for macro shocks to a firm's performance. $Firm\_dum$ represents a vector of firm dummies to capture the performance heterogeneity across firms. $\varepsilon_{i,t}$ is the error term. For all specifications, standard errors are adjusted for clustering at the firm level.

The coefficient on $Pat_{i,t}$ captures the effect of patent output on firms' subsequent performance. If patent output enhances firms' subsequent performance, this coefficient should be significantly positive. Since both $FP_{i,t+3}$ and $Pat_{i,t}$ are normalized by the same denominator (i.e., total assets in year *t*), the coefficient also represents how one more unit of patent output influences a firm's subsequent sales growth and net profits in the unit of 10 million yuan.[2]

[2] To make its coefficient more interpretable, we multiply $Pat_{i,t}$ by 10 million.

Table 2
Patenting effects on firm performance, baseline estimations.

Dependent variable	(1) Sales growth, t + 3	(2) Net profit, t + 3	(3) Sales growth, t + 3	(4) Net profit, t + 3
Patent count, t	.026	.0023		
	(.66)	(.32)		
EST invention, t			.18	.047
			(.35)	(.29)
EST utility, t			2.6**	.67*
			(2.5)	(1.7)
Other invention, t			.041	.0061
			(.98)	(.7)
Other utility, t			−.62	−.17
			(1.2)	(1.5)
Ln(Total assets), t	−.26***	−.079***	−.26***	−.079***
	(12)	(14)	(12)	(14)
Leverage, t	−.094	.02	−.094	.02
	(1.4)	(1)	(1.4)	(.99)
Fixed asset ratio, t	−.16*	−.052*	−.15*	−.05*
	(1.8)	(1.9)	(1.8)	(1.9)
Year dummies		Yes		
Firm dummies		Yes		
Observations	5727	5727	5727	5727
Adjusted R^2	0.205	0.445	0.205	0.445

Robust standard errors clustered at the firm level are estimated. *t*-statistics are presented in parentheses. *, ** and *** represent significance levels of 10%, 5% and 1%, respectively.

5.2. Baseline regressions

Table 2 presents the estimation results of Eq. (1). In column 1, the first model uses $Sales\_growth_{t+3}$ as the dependent variable. In column 2, the second model uses Net_profit_{t+3} as the measure of firm performance. As shown in both models, total citation counts are insignificantly related to both performance measures. To further explore which part of the total citation count may contribute to firms' subsequent performance, we split the total citation count into four citation counts, namely EST invention, EST utility, other invention, and other utility, and repeat both regressions. As shown in columns 3 and 4, the coefficient on EST utility is positive and significant at the 5% and 10% level, respectively. The magnitude of these coefficients indicates that with one more EST utility citation, sales growth and net profits three years later will increase by 26 million and 6.7 million yuan, respectively.[3] This effect is thus also economically significant. The magnitude of this effect seems reasonable given the fact that approximately one million dollars have to be invested to generate one patent in renewables, as documented by Bettencourt et al. (2009). Only EST utility citation stands out, maybe because at the early stage of a new industry (e.g., the green industry), innovative firms have an advantage over those in mature industries.

In contrast, it is interesting to find that the coefficients on EST invention are insignificant, though these coefficients are positive. It seems counterintuitive at first glance. However, as we have discussed in the hypothesis development, there are factors that may make the correlation negative. Moreover, it is likely that some inventions may take the form of utility-model instead of invention patents since the firm may feel it is more important to obtain timely protection from the SIPO than to obtain more invention patents. In this sense, we do not take for granted that invention patents must be more valuable than utility-model patents. By using citation counts, we have already taken patent quality into account to make these two types of patents comparable: though one utility-model patent is not comparable to one invention patent, it is reasonable to regard the number of citations that they receive as comparable.[4]

For practitioners, it may be interesting to have some idea of how valuable a granted patent is regarding its contribution to firm performance. We thus use patent counts instead of citation counts and rerun the regressions of Table 2 (not reported). The coefficients on EST utility remain positive, but the significance turns marginal. Its magnitude indicates that with one more EST utility patent, sales growth and net profits three years later will increase by 19 million and 4.6 million yuan, respectively. However, one should interpret these numbers with caution due to the insignificance of the coefficients. This insignificance also further confirms our choice of using citation counts: simple patent counts are less precise in measuring patent output because of the heterogeneity of patent quality.[5]

5.3. Dynamics of the relationship

Even though our model setting is based on the conventional wisdom in the literature, it is possible that the length of the lag period is somewhat different in China. To obtain some idea of the dynamics, we use firm performance in different years as the dependent variable and rerun the baseline regressions in Table 3.

In columns 1–3, we use $Sales\_growth_{t+2}$, $Sales\_growth_{t+3}$, and $Sales\_growth_{t+4}$ as the dependent variable, respectively. To be consistent, all these variables are normalized by total assets in year *t*. When $Sales\_growth_{t+2}$ is used (column 1), none of these four patenting measures is significant, suggesting that our baseline setting is acceptable. The insignificance when $Sales\_growth_{t+2}$ is used makes us more confident that our specification of using $Sales\_growth_{t+3}$ is appropriate. When $Sales\_growth_{t+4}$ is used (column 3), the coefficient on EST utility remains positive but significant only at the 10% level. The magnitude is even larger than that when $Sales\_growth_{t+3}$ is used (we replicate the result in column 2). However, one should not over-interpret this increase. One reason is that there may be some magnification of the effect. Specifically, EST utility citation counts in year *t* should positively predict EST utility citation counts in year $t+1$, which influence $Sales\_growth_{t+4}$ if the setting of Eq. (1) is correct. In this way, it is not surprising that EST utility citation counts in year *t* have a magnified effect on $Sales\_growth_{t+4}$. Therefore, one may conclude that the effect may still exist in year $t+4$. However, one should be cautious about concluding that the magnitude of this effect in year $t+4$ is clearly revealed by the coefficient.

Additionally, we use net profits instead of sales growth and repeat the regressions of columns 1 to 3. In column 4, Net_profit_{t+2} is used as the dependent variable. Again, we do not see significant effects from any citation count. In column 6, when Net_profit_{t+4} is used as the dependent variable, the coefficient on EST utility remains significantly positive, indicating that the effect on profitability may last for some

[3] To rule out the possibility that our major result is driven by that firms having EST patents are also later better performed, we rerun the regressions of columns 3 and 4 by including an EST patent dummy. The dummy is equal to one if the EST citation count of the firm-year is positive; otherwise, it is zero. With the inclusion of this dummy, our major result barely changes.

[4] One may be concerned that using total assets as a control variable is problematic given that the same variable is also used to normalize the dependent variable. As a robustness check, We replace ln(total assets) with ln(total sales) to control for firm size. Our major result remains unchanged, indicating that the inclusion of ln(total assets) does not drive the positive relationship between *EST Utility* and firms' subsequent performance.

[5] One concern may be that the significance is still driven by outliers, given that the variations of performance variables are generally large. To further rule out this possibility, we winsorize the performance variables at the 5% level and rerun the regressions of Table 2 (not reported). Our major result remains unchanged. Another concern is that there may be some unobservables that are correlated with both patent output and firm performance. Particularly, lagged performance influences current performance and may be correlated to firm patenting. Following Artz et al. (2010), we include the lagged performance variable and rerun the regressions (not reported). Our major result persists.

Table 3
Lagged effects of patenting on firm performance.

Dependent variable	(1) Sales growth, t + 2	(2) Sales growth, t + 3	(3) Sales growth, t + 4	(4) Net profit, t + 2	(5) Net profit, t + 3	(6) Net profit, t + 4
EST invention, t	−.082	.18	1	−.024	.047	.029
	(.26)	(.35)	(1.1)	(.21)	(.29)	(.15)
EST utility, t	.42	2.6**	5*	−.29	.67*	.76*
	(.72)	(2.5)	(1.8)	(.87)	(1.7)	(1.8)
Other invention, t	−.0088	.041	.089	−.005	.0061	−.0062
	(.3)	(.98)	(1.3)	(.53)	(.7)	(1)
Other utility, t	.033	−.62	−.13	.048	−.17	−.13
	(.12)	(1.2)	(.18)	(.8)	(1.5)	(1)
Ln(Total assets), t	−.21***	−.26***	−.33***	−.058***	−.079***	−.1***
	(12)	(12)	(12)	(13)	(14)	(12)
Leverage, t	−.09	−.094	−.041	.019	.02	.027
	(1.4)	(1.4)	(.49)	(.99)	(.99)	(1.1)
Fixed asset ratio, t	−.12	−.15*	−.18*	−.051**	−.05*	−.035
	(1.5)	(1.8)	(1.7)	(2.4)	(1.9)	(1.1)
Year dummies			Yes			
Firm dummies			Yes			
Observations	5727	5727	5727	5727	5727	5727
Adjusted R^2	0.210	0.205	0.203	0.424	0.445	0.470

Robust standard errors clustered at the firm level are estimated. *t*-statistics are presented in parentheses. *, ** and *** represent significance levels of 10%, 5% and 1%, respectively.

time.

5.4. Underlying mechanisms

Having established a positive relationship between EST utility citation counts and firm performance among manufacturing firms, we further explore the underlying mechanisms through which EST utility citation counts enhance firm performance. We hypothesize that EST utility citation counts boost firm performance through two mechanisms: state ownership and regulation enforcement. Accordingly, we examine how EST utility citation counts influence firm performance differently in the cross-section.

5.4.1. State ownership and patenting effect

As SOEs have a closer relationship with the government and thus are more likely to win environment-related projects promoted by the government, we expect that the green-patenting effect on firm performance should be more pronounced in SOEs than that in non-SOEs (i.e., H2). Table 4 estimates the patenting effect on firm performance among SOEs and non-SOEs, respectively. We define a firm as an SOE if its ultimate controller is the state or a local government agency; otherwise, it is a non-SOE (in this case, the ultimate controller is most often an individual). As shown, the coefficient on EST utility is only significantly positive among SOEs. Moreover, its magnitude is much higher than that among non-SOEs, confirming our hypothesis that the green-patenting effect on firm performance is more pronounced among SOEs. This suggests that SOEs are more capable of taking full advantage of EST utility patents to obtain projects with environmental requirements, which are government related. [6]

Table 4
Patenting effects on firm performance, SOE vs non-SOE.

State ownership / Dependent variable	(1) SOE Sales growth, t + 3	(2) Net profit, t + 3	(3) Non-SOE Sales growth, t + 3	(4) Net profit, t + 3
EST invention, t	−.38	−.17	.39	.21
	(.53)	(1.1)	(.76)	(.71)
EST utility, t	4.2***	1***	1.2	.22
	(5.2)	(2.9)	(.56)	(.38)
Other invention, t	.02	−.00095	.22**	.082
	(.73)	(.22)	(2)	(1)
Other utility, t	.048	−.092	−1.1	−.2
	(.063)	(.5)	(1.5)	(1.5)
Other controls		Yes		
Year dummies		Yes		
Firm dummies		Yes		
Observations	3693	3693	2034	2034
Adjusted R^2	0.234	0.487	0.141	0.374

Robust standard errors clustered at the firm level are estimated. *t*-statistics are presented in parentheses. *, ** and *** represent significance levels of 10%, 5% and 1%, respectively.

It is also interesting to find that when sales growth is examined, the coefficient on *Other Invention* is significantly positive among non-SOEs but insignificant among SOEs (column 3). It highlights the difference between EST patents and other patents in terms of how they realize their performance enhancement effects: while the enhancement effect of EST patents relies on a close relationship to the government, such an effect of other patents is more market oriented.

5.4.2. Regulation enforcement and patenting effect

As we have discussed, environmental protection has been more strictly enforced since 2006. Therefore, according to H3, it is reasonable to expect the green-patenting effect to be more pronounced after 2006. Since our major results exist only among SOEs, we rerun the regressions by period among these SOEs in Table 5. Specifically, we include two groups of citation counts, namely *Citation Counts before 2003* and *Citation Counts after 2003*. *Citation Counts before 2003* are equal to the value of citation counts if the year is before 2003; otherwise, they are zero. *Citation Counts after 2003* are equal to the value of citation counts if it is after 2003 (including 2003); otherwise, they are zero. As shown, only the coefficient on *EST utility after 2003* is significantly positive, whereas the coefficient on *EST utility before 2003* becomes insignificant. Therefore, we confirm that regulation enforcement plays an important role in the positive relationship between green patenting and firm performance.

Jaffe and Palmer (1997) show that environmental regulation can impose significant positive impacts on firms' innovation input. Our results here further expand their findings to show that in China, firms' green innovation can generate more benefits with stricter environmental regulation. The passage of Renewable Energy Law (REL) not only provides legal support to green/sustainable development, but also

[6] We rerun the regressions by regions and find that the positive relationship is driven by SOEs in the eastern area. It seems that the extent of regional development may also play a role.

Table 5
Patenting effects on firm performance among SOE firms, by period.

Dependent variable	(1) Sales growth, t + 3	(2) Net profit, t + 3
After 2003:		
EST invention, t	−.45	−.13
	(.63)	(.91)
EST utility, t	4.2***	.98***
	(5.3)	(2.7)
Other invention, t	.021	−.0016
	(.74)	(.39)
Other utility, t	.045	−.092
	(.059)	(.5)
Before 2003:		
EST invention, t	2.3	−1.6
	(.44)	(1.2)
EST utility, t	4.7	3.2
	(.76)	(.88)
Other invention, t	−.36	.74*
	(.23)	(1.7)
Other utility, t	1.2	−1.5
	(.24)	(1.3)
Other controls	Yes	
Year dummies	Yes	
Firm dummies	Yes	
Observations	3693	3693
Adjusted R^2	0.233	0.487

Robust standard errors clustered at the firm level are estimated. *t*-statistics are presented in parentheses. *, ** and *** represent significance levels of 10%, 5% and 1%, respectively.

is an important signal to the general direction of policy importance. For example, in Zhang et al. (2016b), renewable energy development has become faster after the launch of REL.

6. Conclusions

Seeking a green growth path is crucial for achieving sustainability. This is especially relevant to China, where the country is experiencing enormous pressure from the conflict between environmental sustainability and economic growth. The Chinese government has invested heavily to develop green technology and promote innovation in recent years. The main question is whether macro-level progress is consistent with micro-level incentives: in other words, whether innovation towards green growth paths by firms improves their performance.

Based on the existing literature and the fundamental arguments outlined above, this paper established three testable hypotheses on the green innovation-performance relationship. Empirically, using listed firm-level data for the 2000–2010 period, we found statistically significant evidence supporting the so-called Porter Hypothesis that green innovation can improve firms' subsequent performance (i.e., higher sales growth and higher net profits). Among the different types of green innovation, green utility-model innovation is the main driving force for the positive relationship. Furthermore, the economic benefits derived from green innovation are mainly valid for SOEs and become significant after a favourable regulatory environment is introduced (i.e., the implementation of the Renewable Energy Law in 2006). In general, our empirical results confirmed the initial setup of the paper with evidence showing clear economic incentive for firms to engage in environmental friendly innovations. Given the general consensus that innovation can boost economic growth, our empirical findings confirms that green innovation behaviours of manufacturing firms in China can induce long term benefits for sustainable economic performance.

Our paper makes clear contributions to augment the relevant literature. Using citation counts has clear advantages over R&D or simple patent counts since the quality of innovation can be taken into account. A number of policy implications can be derived from our empirical findings. Investing in clean technology by individual firms is not only consistent with country-level strategic development but also has economic benefits. It provides clear motivation for more firms to engage in environmentally friendly innovation.

While only SOEs benefit from green innovation at this stage, policymakers need to adjust their bias and provide more incentives to private corporations. It is possible that SOEs can gain additional benefits (e.g. subsidies) with green innovation, government needs to realize that private sectors are critically important and supports to private enterprises for encouraging green innovation are needed.

After the passage of REL in 2006, Chinese government has implemented a series of rules and policy instruments to encourage sustainable development. There are, however, needs for further improvements to the regulatory environment in favour of green growth. Learning from the experiences from developed economies can be helpful. Market oriented mechanisms are necessary to reconcile the cost and benefit conflicts in private firms. Finally, although our results are based on a sample of Chinese listed manufacturing firms, we believe that the main findings can be generalized to relevant issues in other countries, especially studying similar topics in other developing economies.

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