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Effects of urban environmental policies on improving firm efficiency: Evidence from Chinese new energy vehicle firms

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ABSTRACT

This paper explores the determinants of the development of the new energy vehicles (NEVs) industry in China, which is important to the government in controlling the environmental pollution associated with the urbanization process. Urban governance policies have played an important role in promoting the sustainable development of cities. In this study, we investigate the dynamic effects of such policies and of financial support on the relationship between firm size and efficiency in the NEVs industry. These policies include subsidies from state and local governments during the production and promotion of NEVs. The sample includes an unbalanced panel data set of 148 firms closely related to the automobile industry in the Zhongguancun Science Park from 2005 to 2015. A data envelopment analysis model and a random effects model are used to test the hypotheses, and the results show that both government policies and financial support are beneficial in increasing the efficiency of large NEVs firms. However, small firms cannot benefit from these policies. To promote the technological progress of the NEVs industry, it is highly important to provide further government support for the small NEVs firms that play a leading role in the development of emerging technologies. Only in this way can the government create a healthy market environment for the future of NEVs industry, and reduce the pollution in urban areas.

1. Introduction

Environmental governance during its period of urbanization is a great challenge in China, as the government needs to coordinate the interests of diverse subjects, adopt technologies and institutional improvements to facilitate energy saving and emissions reduction, and establish a green economy for sustainable growth (Mol and Carter, 2006). Thus, the government has adopted new urban governance policies to promote the sustainable development of cities. One area of focus in this regard has been improving the fuel utilization of traditional automobiles and seeking alternative vehicle fuels, such as the application of clean energy in new energy vehicles (NEVs) (Ou et al., 2010). A series of laws, regulations and policies have been promulgated for the development of the NEVs industry in China. During 2009–2011, government ministries (including the Ministry of Finance and the Ministry of Science and Technology) conducted pilots to demonstrate and promote NEVs. In 2012, the central government formally proposed the Energy Saving and NEVs Industry Development Plan (2012–2020), along with other policies, which have already been effective in stimulating the further development of the NEVs industry (Cull et al., 2017; Lee, 2018).

However, many challenges exist in the development of NEVs, especially in relation to electric vehicles (EVs). The key challenge for developing EVs and overcoming the bottleneck in energy transformation is battery power (Lin et al., 2013; Wu et al., 2015). Another challenge arises from a lack of the infrastructure construction of NEVs, such as all kinds of charging station. Furthermore, all NEVs firms face a serious problem in promoting technology innovation and production efficiency because of the fierce competition, given that this field has attracted a great deal of attention from researchers. As a result of these problems, many

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scholars consider that the development of NEVs requires government policy support. More broadly, the government should implement comprehensive supporting policies to encourage the development of the new energy industry, and to turn China's development path in more sustainable directions (e.g., see Green et al., 2014).

In this study, using the example of the NEVs industry, we explore whether China should increase government support and ensure more effective environmental governance, based on China's recent performance in regard to environmental protection. Previous studies have indicated that government facilitation, including the provision of information about products, markets and innovation, and assistance in arranging loans, is positively associated with firm efficiency and can assist some firms to overcome market failures in the early stages of development. Specifically, in this study, we wish to explore whether financial support from governments is beneficial in overcoming firms' internal barriers to the implementation of cleaner production, and whether stricter regulations may strengthen enforcement of cleaner production. Moreover, we will explore whether the benefits of policy support to NEVs firms depend on firm and industry characteristics.

We attempt to fill some gaps in the existing research, as few studies have focused neither on the asymmetric effects of government policies on NEVs firms, depending on firm size, nor on the reasons for such asymmetric effects (Zhang and Wen, 2008; Zhu and Geng, 2013; Kaoru et al., 2017; Cull et al., 2018). Our study attempts to fill this gap using data from Zhongguancun (ZGC) Science Park, which is one of the most promising science parks in China. The NEVs firms in this area are strongly representative for other NEVs firms across China. By analyzing changes in firm efficiency over time, using a random effects model, we explore the different policy effects on different size automobile firms and obtain some implications.

Specifically, firm efficiency in this study is defined as the output–input ratio of a firm, following research by Debreu (1951), Koopmans (1951) and Farrell (1957), which calculated the efficiency of a firm as the ratio of actual inputs to optimal inputs. Researchers use this non-parametric framework to evaluate the efficiency adjusted for greenhouse gas (GHG) emissions, and find that by modifying the mix of polluting inputs, farmers could offset more than 35% of their total inefficiency (Dakpo et al., 2017). At present, the nonparametric method is the most common way to calculate the efficiency boundary of firm innovation, which is used to estimate the relative efficiency of multiple input indicators and multiple output indicators. We utilize input indexes for a NEVs firm's innovation process, including research and development (R&D) staff and R&D expenditure, and the output indexes are measured by the patents and new product sales of a NEVs firm.

The rest of the paper is organized as follows: Section 2 puts forward the hypotheses based on the literature review. Section 3 presents the research design and methodology. Section 4 analyzes the empirical results of the random effects model, and discusses the policy implications. Finally, the conclusion is presented in Section 5.

2. Literature review and hypotheses

2.1. Firm size as the determinant of a NEVs firm's efficiency

The earliest study arguing for the greater efficiency of small firms is by Williamson (1967), who put forward the idea of "control loss", providing a convincing explanation of large firms' inefficient bureaucratic behavior in nonmarket organizations. Link and Scott (2018) investigated the elasticity of patenting with respect to R&D and the spillover effect on firms. They pointed out that the estimated elasticity varies across different size firms and that the cost of innovation in small firms is reduced because they receive R&D techniques through spillovers, from the R&D centers of their larger counterparts and universities.

In contrast, Acs and Audretsch (1987) considered that because relative innovative efficiency depends mainly on firm size, market concentration and the entry barriers of the industry, large firms usually have the innovative advantage in industries that are capital-intensive, concentrated and highly unionized. Cohen and Klepper (1996) proved that the returns to process R&D depend more on firm output, giving larger firms an advantage, as their R&D costs can be spread over a larger output. Griffin and Hauser (1996) provided considerable empirical evidence to demonstrate that complementarity between R&D and marketing enables a large firm to increase its chances of success or the economic returns from new product developments. Hanousek et al. (2017) considered the impact of foreign ownership and the gender of managers on firm efficiency. As the divergent views in the literature indicate, in reality the determinants of firm efficiency are complex and controversial. Studies that specifically discuss NEVs in this regard include Egbue and Long (2012), who identified potential socio-technical barriers to consumer adoption of NEVs, and Krause et al. (2013), who focused on the extent of consumer recognition of NEVs and the current policies to encourage their purchase and use, in influencing the decision to purchase a vehicle.

In this study, firm size is considered as an important factor that may influence the efficiency of firms in the NEVs industry. Compared with large firms, which have abundant resources, small firms generally face more severe financial constraints, resulting in exit rates being much higher among small firms. Medium-sized firms are also considered a risk, with the unstable production efficiency (Pham and Takayama, 2017; Lopezmartin, 2017).

Similar viewpoints have been expressed in support of a positive relationship between firm size and R&D inputs. Cintio et al. (2017) stated that R&D activities will be more productive in large firms with sophisticated marketing and manufacturing systems. In addition, large firms can earn higher returns on R&D due to the advantages of cost spreading. Legge (2000) argued that large firms have a substantial advantage in being able to sustain an adequately diverse portfolio, and to spread their R&D expenditure during the R&D process. Cintio et al. (2017) argued that the R&D expenditure of a firm can be spread over its output and induced exports; hence, large firms can gain higher returns from their R&D activities. Link and Scott (2018) conducted empirical research on the relationship between firm size and innovative activities and found that the estimated rate of return to R&D activities for small firms is far below that for large firms.

Building on the above research, Chinese scholars have evaluated the efficiency of the automobile market in China. Sun et al. (2011) investigated 29 firms in this market, and found that 26 of them had increasing returns to scale. They pointed out that these firms are increasing their inputs and importing new technology and talent to improve their overall efficiency. Given this, we consider that the size of NEVs firm is positively related to firm efficiency. To verify the existence of scale economies in Chinese NEVs firms, we test Hypothesis 1, as follows:

Hypothesis 1. Large NEVs firms may have a higher level of firm efficiency than do small firms.

2.2. The moderating role of government support

In reality, the efficiency of NEVs firms is not only influenced by the firm's own characteristics, but also by the industrial policy. Government support may be provided in many different ways.

From Porter's competitiveness advantage theory (Will, 2013), the traditional viewpoint is that government plays an important role in encouraging competitive conditions. In addition, some system problems, such as network issues, call for government intervention, as they cannot be solved by market forces (Chaminade and Edquist, 2006). Thus, as researchers have become more aware of market system problems, they have proposed that government should pay more attention to and take actions to deal with such problems. Some researchers have designed scientific methods of appraising government policy. For instance, Melton et al. (2017) developed an evaluation framework based on the likely effectiveness of a package of policies, which provides an accessible tool for policymakers to assess different policy support packages.

Policies relating to subsidization, technical support and infrastructure require urgent improvement. There are many studies on industrial policies and a large body of advice on existing policies. Skerlos and Winebrake (2010) considered that a subsidy policy would have higher social benefits at an equal or lower cost if tax credits were offered at different levels depending on consumer income and the location of purchase. Green et al. (2014) found that policies featuring a mainstream market bias are inefficient and costly, and they insisted that policies, rather than focusing on mainstream consumers, should focus on niche markets, such as markets with early adopters, including green consumers. Li and Sun (2016) found that macroscopic policies are associated with a high level of consumers' satisfaction, whereas industry management policies are associated with a low level.

Commonly, government policies influence the relationship between firm size and efficiency. For instance, Yang (2013) found that government policy may become a monopoly resource for large firms, which find it easy to obtain support and form a monopoly market structure, which leads to a loss of social welfare. Government policy can raise entry barriers for small firms, encouraging mergers and acquisitions, centralizing resources and consolidating the advantage of large firms (Geroski and Jacquemin, 1985). Thus, government policy supporting NEVs firms in a country with a tradition of centralization, such as China, can help large firms to maintain their advantages, increase their efficiency and play a leading role in the NEVs markets.

Another general means of government support is subsidies on R&D. The government takes on the dual role of investor and facilitator through industry policy by financially supporting firms' R&D activities and stimulating networking activities among organizations involved in the innovation process. Using a nonparametric matching approach, Almus and Czarnitzki (2003) compared the R&D spending of subsidized firms with nonsubsidized firms and found that the R&D intensity of the former was 4% higher. In addition, Hall and Bagchi-Sen (2007) found that government funding for research and technical training was positively associated with the intensity of R&D in US biotechnology firms. However, many researchers have argued that large firms with access to public financing were more likely to undertake R&D activities than those without such access. Hottenrott et al. (2017) found a positive direct effect from R&D subsidies on net R&D spending of firms, and also found that the magnitude of the treatment effects depends on firm size. Cull et al. (2018) found that small firms with weak access to and knowledge of resources and markets are in urgent need of government support, including provision of information and assistance in arranging loans. From the conclusions of the researchers surveyed above, it is evident that government financial subsidies have not provided sufficient support to small firms, which face an inherent shortage of internal resources.

From the arguments above, it is evident that the effect of government policies and financial subsidies on firm efficiency depends on firm size. Hence, this study postulates the following two hypotheses:

Hypothesis 2a. Government policies and regulations enhance the positive relationship between firm size and efficiency, which means that large firms may benefit more than do small firms from policies and regulations.

Hypothesis 2b. Government financial subsidies enhance the positive relationship between firm size and efficiency, which means large firms may benefit more than small firms from these subsidies.

Thus, it is obvious that government support is more beneficial for large firms that are already abundant in resources and highly competitive. In contrast, government support may somewhat harm efficiency improvements in small firms, hindering their development. With the assistance of government support, large firms may be able to exclude the small firms and to form a monopoly or oligopoly, which would be harmful to the development of the NEVs industry.

3. Method

3.1. Data description

Our sample involves an unbalanced panel data set of 148 firms closely related to the NEVs industry in ZGC Science Park from 2005 to 2015, including a NEVs producer, firms in the NEVs industry chain and competitors in the NEVs consumption market. As ZGC Science Park is one of the most promising science parks in China, the NEVs firms in this area are highly representative for other NEVs firms across China. The data are collected from the management committee of the Zhongguancun Science and Technology Park, and includes all the annual reports of the NEVs firms. This longitudinal data set, which extends over 11 years, is useful for analyzing the growth and the change of automobile firms in industry clusters over time. Information relating to a firm's product development, financial situation, human resources and technical expenditures is included in the sample. All NEVs firms for which there is the required information to calculate firm efficiency are included in the sample. Using the full sample enables us to avoid some selection bias problems.

The analytic framework for our research, including definitions of all the variables, is outlined in Table 1. The independent variable in this study is firm size. Four categories of firms are included in the sample: large, medium, small and micro firms. Size is measured by the revenue, assets and staff numbers of a firm. According to the State Statistics Bureau's standard, different industries have their own definitions of firm size. In the sample, micro and small firms account for about 23.65% and 55.41% of firms, respectively, whereas medium and large firms account for about 15.54% and 5.41%, respectively.

The moderating variables in this study include the strength of the government's supporting policies and the government's financial support. In recent years, China has treated the NEVs industry as a strategic emerging industry and has promulgated a series of laws, regulations and policies to promote the continuous growth of the NEVs and power battery industries. Driven by the government's long-term development plan, the NEVs industry has entered into its "golden age". From 2009 to 2011, some ministries, including the Ministry of Finance and the Ministry of Science and Technology, have formulated and promulgated a series of supporting policies to promote the development of NEVs firms.

In this study, we collect detailed records of government support for NEVs firms, including the policies each year and the financial

Table 1
Description of variables.

Variables	Measurement
Firm size	Measured by revenue, asset and staff numbers, including four categories: large, medium, small and micro firms.
Strength of government supporting policy	Through the number of laws, regulations and policy provisions which support the new energy vehicles firms and are introduced by different departments such as the State Council, Ministry of Industry, Ministry of Finance and other ministries from 2005 to 2017, the degree of annual policy is able to be calculated (Lv et al., 2016).
Government financial subsidy	Defined by whether the firm has received the financial support from government *t*, which is a 0–1 variable.
Firm efficiency	Calculated by CCR-DEA model with multiple inputs and multiple outputs. The inputs include all the expenditures and personnel, while the outputs include new product sales and total sale income.
Firm age	Firms may have accumulated more experience and a larger knowledge base, thus more likely to have higher level of innovation efficiency as firm age increases.
Science parks that firms belong to	Referring to the official standards of ZGC management committee, we divided 16 science parks in ZGC into 3 categories: earliest-established clusters, mid-term-established clusters and recent-established clusters.
Ownership	The property right of controlling shareholder of sample firms, including state-owned and non-state-owned.
Type of firm's main business	Type of main business is used to reflect firms' development strategies, which contains 2 categories: Vehicle manufacturing and parts manufacturing.
High-tech firms	This is a dummy variable to evaluate if the firm is certified as high-tech firms by the management committee of ZGC parks.
Increment of R&D investment	Increment of R&D investment is defined as follows: $\frac{R\&D\ investment\ of\ year\ 1 - R\&D\ investment\ of\ year\ 0}{the\ sum\ of\ R\&D\ investment\ in\ year\ 0\ and\ year\ 1}$

subsidies received by each NEVs firm. Based on these data, the study empirically tests all the hypotheses outlined above. There are various supporting policies of relevance. The central government has formally proposed the Energy Saving and NEVs Industry Development Plan (2012–2020). It has been accompanied by many other policies to stimulate the further development of the NEVs industry, including the Notice on Continuing the Promotion and Application of NEVs (2013–2015) issued by the Ministry of Finance in 2013 and the central government's Accelerating the Popularization and Application of NEVs in 2014. These and other policies and plans that came into effect during 2015–2017 are listed in Table 2. These policies establish and improve the standard system of resource utilization by the NEVs industry and clearly point out directions for development, paving the way for the booming development of the industry and its firms.

The control variables include a group of firm characteristics that may affect a firm's efficiency. These characteristics include firm age, the science park to which the firms belong and the ownership and type of a firm's main business. The descriptive statistics and the correlations of these variables are listed in Tables 3 and 4. The Pearson test, which is a measure of the linear correlation between two variables, is used in this study. From the tables, it can be seen that most firms in the sample are micro- and small-sized firms (as noted above) and that the average firm age is around 8 years.

Table 3
Descriptive statistics of variables in empirical study.

Variable	Mean	Std. Dev.	Min	Max
Size	2.055	0.725	1.000	4.000
Strength of policy	0.024	0.016	0.006	0.051
Financial subsidy	0.857	0.350	0.000	1.000
Firm age	8.180	6.515	0.000	57.000
Earlier cluster	0.153	0.360	0.000	1.000
Midterm cluster	0.683	0.466	0.000	1.000
Ownership	0.042	0.202	0.000	1.000
Type of main business	0.071	0.258	0.000	1.000
High-tech firms	0.141	0.348	0.000	1.000
Increment of R&D investment	−0.021	0.453	−1.000	1.000

3.2. Research design

In our study, we first utilize a data envelopment analysis (DEA) model. DEA is a nonparametric method to empirically measure production frontiers and we use the DEA model to calculate the efficiency of firms, which is the dependent variable in the regression model. Then, we incorporate the random effects method used for the analysis of panel data into the regression model to exclude the impact of time-invariant factors, such as the strength of supporting policies. Moreover, the random effects model can eliminate the individual-specific unobserved effects. Finally, we use the Tobit model as a robustness check method.

Table 2
Summary of support policies of NEV industry.

Policy and Plan	Department	Classification	Year
Energy Saving and NEV Industry Development Plan (2012–2020)	The State Council	Industrial Policy	2012
Interim Measures for the Management of Financial Incentive Funds for NEV Industry Tech-Innovation	The Ministry of Finance, etc.	Fiscal Policy	2012
Notice on the Continuing Application of NEVs	The Ministry of Finance	Fiscal Policy	2013
Guidance on Accelerating the Promotion and Application Of NEVs	General Office of the State Council	Industrial Policy	2014
Notice on the Electricity Pricing Policy of Electric Vehicles	National Development and Reform Commission	Industrial Policy	2014
Guidance on Accelerating the Construction of Electric Vehicle Charging Infrastructure	General Office of the State Council	Industrial Policy	2015
Notice on the Financial Support Policy for the Promotion and Application of NEVs in 2016–2020	The Ministry of Finance, etc.	Fiscal Policy	2015
Notice on Accelerating the Promotion and Application of NEVs in the Transportation Industry	The Ministry of Communications	Industrial Policy	2015
Regulation of the Average Fuel Consumption of Car Company and the NEV Points Management	Ministry of Industry and Information Technology, etc.	Industrial Policy	2017
Administration of Automotive Loans Procedures (revised in 2017)	People's Bank of China, etc.	Credit Policy	2017

Table 4
Correlations of all the variables in regression model.

		1	2	3	4	5	6	7	8	9	10
1	Size	1									
2	Strength of policy	0.156***	1								
3	Financial subsidy	−0.140***	−0.352***	1							
4	Firm age	0.333***	0.268***	−0.245***	1						
5	Earlier- cluster	−0.188***	−0.078	0.102**	0.024	1					
6	Midterm-cluster	0.172***	0.029	0.031	−0.081	−0.623***	1				
7	Ownership	0.339***	0.062**	−0.212***	0.264***	0.08	0.031	1			
8	Type of main business	0.393***	0.094***	−0.187***	0.296***	−0.086*	0.04	0.359***	1		
9	High-tech firms	0.256***	0.203***	−0.523***	0.258***	0.052	−0.059	0.289***	0.337***	1	
10	Increment of R&D investment	0.099*	0.136***	−0.076	−0.007	−0.02	0.033	0.038	0.002	0.087*	1

Note: the standard error of each estimated value is provided in brackets; *** represents $p < 0.01$, ** represent $p < 0.05$ and * represents $p < 0.1$.

The random effects model assumes the characteristics and effects of the items change with the sample, based on the fact that our data are part of an aggregation. Thus, in our model, we incorporate an item that reflects the random effect and is denoted by a_i, which is uncorrelated with the independent variables x_{it}. Finally, we can obtain a reasonable partial effect of the explanatory variables within a wide range by using the random effects model. Based on the above analysis, we can derive the econometric model shown in Equation (1).

$$y^* = \beta_0 + \beta_1 size + \beta_2 governsupport + \beta' x_{it} + \mathrm{a_i} + u_{it}, \\ E(\mathrm{a_i}|x_{it}) = E(\mathrm{a_i}) = 0 \tag{1}$$

As stated above, the dependent variable y^* is firm efficiency, calculated using the Charnes, Cooper and Rhoades DEA model, with multiple inputs and multiple outputs, which is used to estimate the productive efficiency of decision-making units. This model assumes that, under the restriction of constant returns to scale, all observed production combinations of inputs and outputs that represent the efficiency of the decision-making units, can be scaled up or down proportionally. The measurement of input-output factors in the DEA model can be seen in Table 5. We are interested in the partial effect of size and the government support policy on firm efficiency, which is measured by the estimation of β_1 and β_2. Items of x_i denote other controlling variables, such as firm age and the ownership.

The moderating variables in this study include the strength of government policies and the existence of financial subsidies. In recent years, China has promulgated a series of laws, regulations and policies for the NEVs industry, establishing it as a strategic emerging industry, and promoting the continuous growth of the NEVs and power battery industries. During 2009–2011, certain ministries, including the Ministry of Finance and the Ministry of Science and Technology, have conducted demonstration pilots to promote NEVs. Then, in 2012, the central government formally proposed the Energy Saving and NEVs Industry Development Plan (2012–2020), along with a range of supporting policies, to stimulate further development of the NEVs industry.

Based on the existing research, we use two dimensions to define the strength of government policy in terms of the power of the government, to promote the development of the NEVs industry, namely the policy category and the enacting department. If supporting policies are issued by a higher level of government, or if many such policies have been established within a given year, this indicates that the supporting policies benefiting NEVs firms are stronger in that specific year. We develop an assignment number system based on these two dimensions, as explained below. According to these criteria, i represents the category of policy; t represents the policy year ($t = 2005, 2006 \ldots 2015$); B_i represents the assignment number of the policy in category i; P_{it} represents the number of policies in category i issued in year t; and TP_t expresses the overall strength of the policy in the year t, and the following formula is developed to calculate the strength of policy supporting the NEVs industry: $TP_t = \sum_{i=1}^{n}(B_i \cdot P_{it})$. The assignment of each policy in the formula is defined according to the two dimensions for measuring the policy strength explained above. If the policy is protected by state laws, its assignment number is 3; if it is promulgated by the State Council, its assignment number is 2. If the policy is carried out by the Ministry of Science and Technology, the Ministry of Finance or the Ministry of Industry and Information Technology, its assignment number is 1, which indicates the policy has the weakest implementation capacity. Table 6 shows the assignment system for Chinese policies categorized by the enacting department each year.

4. Results, discussion and implications

4.1. Results

The results of the DEA model are measures of the firms' efficiency levels, which have been used as dependent variables in the random effects model. About 37% of firms in the sample have efficiency levels measured between 0 and 0.2 and about 34% have efficiency of 0.2–0.4. About 14% and 8% of the firms in this sample

Table 5
The measurement of input-output factors in the DEA model.

Input–output factors	Measurement
Innovative inputs (year 0)	
R&D expenditures	the sum of various R&D expenses on scientific and technological innovation
R&D staff	the number of full-time scientists and engineers
Non-innovative inputs (year 0)	
Non-R&D expenditures	the total annual income of a firm minus its profits and R&D expenditures
Non-R&D staff	the total number of employees minus the R&D staff number
Final outputs (year 3)	
New product sales	the revenue of new products for sale developed by a firm
Sales income	The revenue of products and service provided by a firm

Table 6
The assignment of Chinese policies categorized by the enacted department each year.

Assignment	3	2	2	2	2	2	2	1	1	1
Type	National laws	Decisions of the State Council	Opinions of the State Council	Circular of the State Council	Approval of the State Council	Regulations of the State Council	Planning of the State Council	Ministry of Finance	Ministry of industry and information technology	Ministry of science and technology
year										
2017	2			4					4	1
2016		1	5	14				6	22	5
2015			8	2				3	26	6
2014			4	5				5	15	3
2013	1		2	5				1	2	2
2012			6	6				4	19	4
2011	1		3	4		1		1	20	7
2010		2	1	4					16	1
2009			7	1			3		5	2
2008			1	2						1
2007	1			3						2
2006					1					4
2005	1	1	1	1						

have higher efficiency levels, between 0.4–0.6 and 0.6–0.8, respectively. About 7% of the firms have efficiency levels higher than 0.8. Fig. 1 shows the distribution of all firms' efficiency levels. Table 5 shows the measurement of the input–output factors in the calculation of the DEA model.

The regression model in Table 7 shows the results from analyzing the data from ZGC Science Park. From column 1, it can be seen that firm size has a statistically significantly positive influence on firm efficiency ($\beta = 0.171$; $p < 0.01$), which means that each unit expansion of firm size will increase efficiency by more than 15%. From the results in columns 2 to 4 ($\beta = 0.125$, 0.164 and 0.132; $p < 0.01$), Hypothesis 1 is verified. One possible explanation is that the expansion of firm size reduces the fixed cost of technical innovation and technology diffusion, and indicates that the large firm will be more market-oriented, which leads to greater efficiency, as illustrated by Pantouvakis et al. (2017).

Next, further empirical analyses are conducted to verify Hypothesis 2. The variables representing government support are added in models 2 and 3 to investigate the effect of government support on the relationship between firm size and efficiency. The results from these models indicate that the strength of government policy increases the firm-size effect on efficiency, and that financial support also improves the size effect on firm efficiency ($\beta = 0.002$, $p < 0.1$; $\beta = 0.093$, $p < 0.01$), which may be due to the competitive advantages that large firms obtain from government support. From the results, it is clear that government support impacts the firm-size effect on efficiency, which shows that Hypotheses 2a and 2b are both supported.

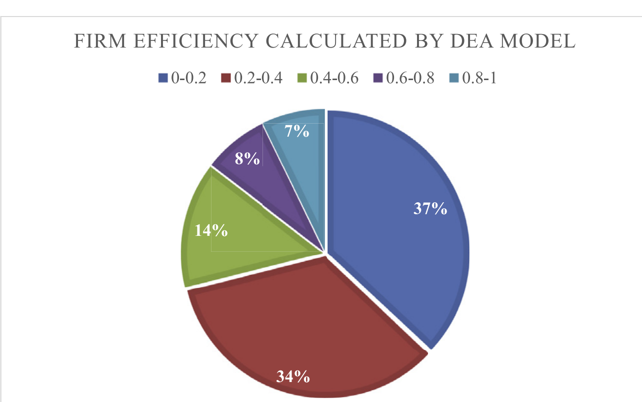

Fig. 1. The distribution of firm efficiency calculated by DEA model.

These results for our Chinese sample are similar to those for the case of Korea in the 1990s. The Korean government promulgated a series of laws and industrial policies to stimulate the manufacturing firms' innovation activities, leading to the take-off of Korea's economy. As analyzed by González and Pazó (2008), the effect of government subsidies and government support on private R&D spending in Korea was positive and significant. Block and Keller (2008) pointed out that, among the top 100 innovations recognized in R&D Magazine between the 1970s and 2006, federal funding had been received by approximately 90% of the US entities that produced award-winning innovations.

To test the moderating role of policies and regulations, this study compares the reaction of sample firms with low or high policy and regulation strengths. As Fig. 2 indicates, when the strength of policy is relatively high, firm size has a more positive effect on the firm's efficiency. Furthermore, this study shows a greater difference between small and large firms in terms of the policy effect on the firm's innovation efficiency. It indicates that the policies and regulations of governments do help to promote the efficiency of large firms, but also widen the gap between small and large firms. Fig. 3 indicates that government financial subsidies significantly moderate the relationship between firm size and efficiency. A simple slope test reveals that the relationship between firm size and efficiency is indeed contingent on government financial subsidies. That is, for the firms that received financial subsidies, firm efficiency greatly improved with the increase of firm size.

In addition, we find that the influence of ownership on efficiency is slightly significant. This result indicates that state-owned firms have advantages that promote their efficiency, which supports the results of Song and Yao (2005). It is easier for state-owned firms in China to obtain a competitive advantage over other firms because of their greater government assistance and supportive policies. Based on this, governments should pay greater attention to ensuring a more even playing field for other firms competing with state firms in the NEVs and other markets. Further, we obtain a statistically positive significant effect for the medium-term cluster factor ($\beta = 0.067$, $p < 0.05$) in column 2, indicating the crucial impact of the science parks in the development of NEVs firms, which is consistent with the research results of García-Granero et al. (2018). It is important to construct an appropriate set of policies in establishing clusters to promote more efficient technological progress of the emerging industries.

Table 7
The results of regression on firm efficiency.

	Firm efficiency				
	(1)	(2)	(3)	(4)	(5)
Size	0.171***	0.125***	0.164***	0.132***	
	(0.022)	(0.020)	(0.022)	(0.020)	
Strength of policy	0.807	0.315			
	(0.934)	(0.816)			
Financial subsidy	0.048		0.042		
	(0.030)		(0.026)		
Size * strength of policy	0.004***	0.002*			
	(0.001)	(0.001)			
Size * financial subsidy	0.159***		0.093***		
	(0.038)		(0.033)		
Firm age	−0.003	−0.002	−0.001	−0.002	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Earlier cluster	−0.008	0.017	0.007	0.022	−0.032
	(0.044)	(0.044)	(0.044)	(0.044)	(0.046)
Midterm cluster	0.048	0.067**	0.060*	0.071**	0.081**
	(0.032)	(0.033)	(0.032)	(0.033)	(0.034)
Ownership	−0.062	−0.063	−0.069*	−0.068*	−0.003
	(0.040)	(0.041)	(0.040)	(0.041)	(0.042)
Type of main business	−0.001	0.029	0.01	0.03	0.090***
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
High-tech firms	−0.023	−0.041	−0.027	−0.041	−0.016
	(0.026)	(0.026)	(0.026)	(0.025)	(0.027)
R&D investment growth	−0.025	−0.026	−0.025	−0.026	−0.006
	(0.026)	(0.027)	(0.026)	(0.027)	(0.028)
Constant	−0.227***	−0.114**	−0.204***	−0.123**	0.101***
	(0.059)	(0.051)	(0.054)	(0.048)	(0.037)
N	381	381	381	381	381
R2	0.2189	0.1694	0.1852	0.1603	0.0593
Chi2	103.15	75.47	84.11	71.01	23.49

Note: the standard error of each estimated value is provided in brackets; *** represents $p < 0.01$, ** represent $p < 0.05$ and * represents $p < 0.1$.

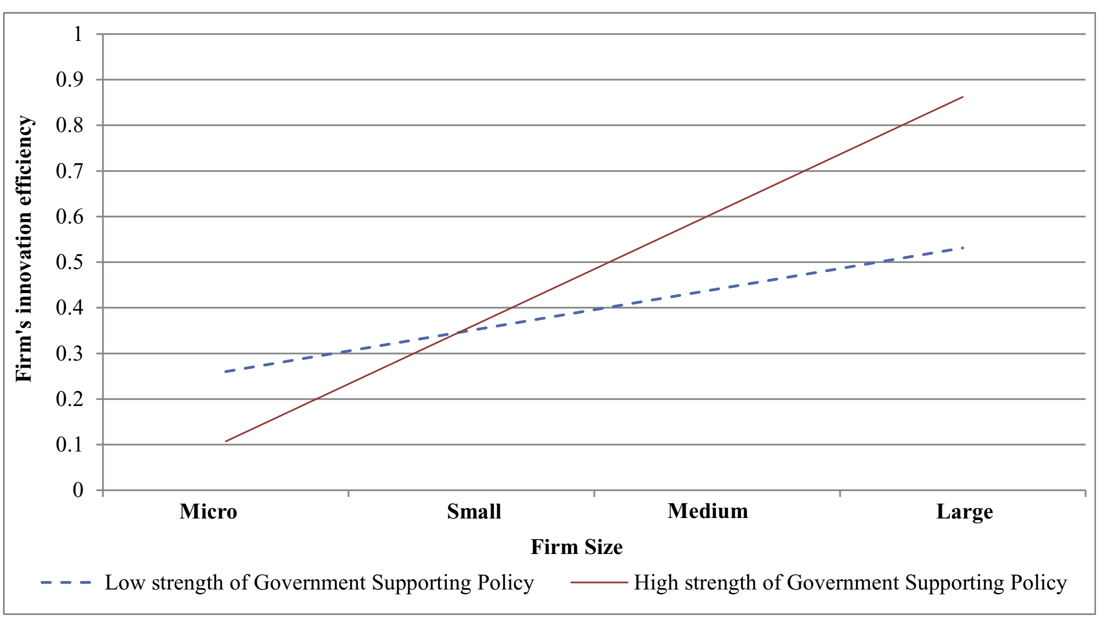

Fig. 2. The moderating role of strength of government supporting policy.

4.2. Robustness check

Moreover, to further strengthen our conclusions, we use a Tobit model to deal with the nonequilibrium problem of our sample data. The Tobit model, which is also a limited dependent variable model, is a statistical model applied and promoted by Tobin (1958) to describe the relationship between a nonnegative dependent variable y and a series of independent variables (or vectors) x. We choose the Tobit model as the values of firm efficiency in our sample are truncation data, which are beyond zero only. Using the Tobit model, we can obtain a nonnegative estimate of y, and determine a reasonable partial effect of the explanatory variables within a wide range. Based on this analysis, we can derive the econometric model in Equation (2).

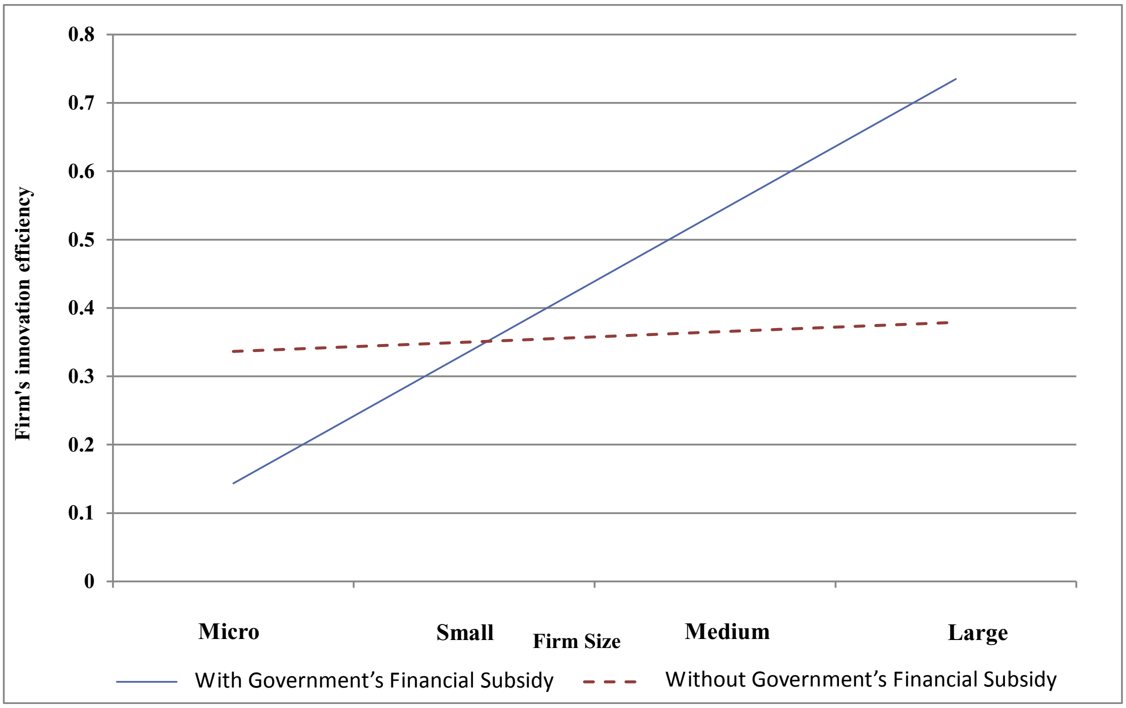

Fig. 3. The moderating role of government financial support.

$$y^*_{it} = \beta_0 + \beta_1 size + \beta_2 governsupport + \beta' x_{it} + u_{it}$$
$$y^*_{it} = y_{it}, \;\; if \;\; y^*_{it} > 0; \qquad y^*_{it} = 0, \;\; if \;\; y^*_{it} < 0 \tag{2}$$

The Tobit model is used as a robustness check of the hypotheses (see Table 8). In comparison with Table 7, the results are quite consistent with the random effects model, and there are no great changes in the coefficients or significance of core variables, indicating that the positive effect of firm size on efficiency remains prominent ($\beta = 0.187$, $p < 0.01$). It is quite clear that a large firm size contributes to reducing the fixed cost of technical innovation and technology diffusion, leading to the greater efficiency of the firm. Furthermore, we obtain a negative impact for firm age ($\beta = -0.002$), showing that old firms are always less innovative and less efficient, which indicates the existence of path dependence. In addition, this test supports the important role of financial subsidies from the government for emerging industries, as the coefficient of financial subsidies is statistically positive and significant in column 1 ($\beta = 0.052$, $p < 0.1$) and column 3 ($\beta = 0.045$, $p < 0.1$).

Our results support the previous research that NEVs firms are indeed experiencing increasing returns to scale (Legge, 2000). As Legge (2000) mentioned, large firms are clearly dominant in terms of innovation and possess an advantage through their R&D investments. They can afford to invest more resources to promote innovation activities and improve their efficiency; as a result, their returns on R&D increase as well. The results are consistent with the conclusion of Sun et al. (2011), who considered that modern firms could expand their business size to spread their R&D costs and reduce transaction costs and thus, potentially improve their production efficiency. In this paper, the conclusions of the existing literature are verified (e.g., see Block and Keller, 2008). These results provide more insight into the development of NEVs firms, indicating that newly-rising firms should seize the chance to expand and benefit from increasing returns to scale. From the results, we also infer that state-owned firms may perform less efficiently than other firms as a result of the rigid regulations governing the innovation process.

Furthermore, we find that strong government policies and the provision of financial subsidies have an obvious positive influence on the size effect ($\beta = 0.005$, $p < 0.01$; $\beta = 0.185$, $p < 0.01$), which indicates that larger NEVs firms benefit more from such policies and subsidies. As Cull et al. (2018) mentioned, firms in emerging industries usually have lesser access to knowledge and resources and rely more on government assistance for technology, information and market support. As García-Granero et al. (2018) stated, a set of eco-innovation government policies may play an important role over the longer term. Based on our study, we suggest that the government should implement more industrial policies and offer more financial subsidies, to encourage technical progress and innovation by firms in emerging industries.

4.3. Discussion and implications

As mentioned above, this study focuses on the asymmetric effects of environmental governance policies on NEVs firms of different sizes. We obtain some interesting implications from our findings. First, our study identifies the important role of innovative firms in the urban environment and finds that governance systems should simultaneously consider industrial innovation and environmental management systems, which is a similar conclusion to that found by Zhou et al. (2018a,b). As Mol and Carter (2006) mentioned, with the rapid growth of industrialization and urbanization, there are more new networks of relationships between government, firms and citizens in society, which makes environmental governance a complex project in China. For this reason, environmental governance should be a matter for markets or private firms rather than the subject of government regulation (Mol and Carter, 2006; Zhang and Wen, 2008). Private firms and citizens should be given more tasks as well as taking more responsibility in environmental governance. There is no doubt that the development of the NEVs industry is beneficial for energy saving and emissions reduction, as well as the remittance of traffic

Table 8
Robustness test: Determinants of firm efficiency estimated by Tobit model.

	Firm efficiency				
	(1)	(2)	(3)	(4)	(5)
Size	0.187***	0.132***	0.177***	0.139***	
	(0.023)	(0.021)	(0.023)	(0.021)	
Strength of policy	0.897	0.353			
	(0.964)	(0.844)			
Financial subsidy	0.052*		0.045*		
	(0.031)		(0.027)		
Size * strength of policy	0.005***	0.002**			
	(0.001)	(0.001)			
Size * financial subsidy	0.185***		0.106***		
	(0.040)		(0.034)		
Firm age	−0.002	−0.002	−0.001	−0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Earlier cluster	−0.012	0.016	0.004	0.021	−0.036
	(0.045)	(0.046)	(0.046)	(0.046)	(0.048)
Midterm cluster	0.048	0.069**	0.062*	0.073**	0.084**
	(0.033)	(0.034)	(0.034)	(0.034)	(0.036)
Ownership	−0.066	−0.067	−0.074*	−0.072*	−0.004
	(0.041)	(0.042)	(0.042)	(0.042)	(0.043)
Type of main business	0.002	0.035	0.014	0.036	0.098***
	(0.035)	(0.035)	(0.035)	(0.035)	(0.036)
High-tech firms	−0.024	−0.043	−0.027	−0.043	−0.016
	(0.027)	(0.027)	(0.027)	(0.026)	(0.028)
R&D investment growth	−0.027	−0.028	−0.026	−0.028	−0.007
	(0.027)	(0.028)	(0.027)	(0.028)	(0.029)
Constant	−0.261***	−0.129**	−0.230***	−0.138***	0.099***
	(0.061)	(0.053)	(0.056)	(0.050)	(0.038)
N	381	381	381	381	381
Chi2	107.420	78.720	88.020	73.260	24.870

Note: the standard error of each estimated value is provided in brackets; *** represents $p < 0.01$, ** represent $p < 0.05$ and * represents $p < 0.1$.

congestion. As Zhou et al. (2018a,b) and Zhu and Geng (2013) explained, the economically and socially developed regions have more efficient pollution and waste treatments, and sufficient supporting policies with financial subsidies from governments to help both small and large firms to overcome internal barriers and reduce financial barriers, which enables them to promote cleaner production and sustainable development. Thus, the crucial impact of urban governance on the development of the NEVs industry and its environmental effect has to be acknowledged.

It is important to investigate and analyze the problems of the NEVs firms in Beijing's science parks and to offer some resolutions for these problems, which could then be promoted nationwide. The influence of clusters or science parks on firm efficiency has aroused attention from many scholars. For instance, Li and Sun (2016) utilized DEA and a Malmquist index to measure the financial efficiency of small- and medium-sized firms in ZGC Science Park from 2012 to 2014, and studied the dynamic change of the clusters. Their results show that after the formation of clusters, the efficiency of firms, measured using all-factor financial efficiency, technical efficiency and scale efficiency, showed an increasing trend across all measures. From the previous studies, it has been shown that science parks have a significant effect on improving the financial efficiency of firms, and provide firms with greater development opportunities. Thus, a key concern of government and policy makers should be how to implement various supporting policies more effectively to benefit both small and large firms in the NEVs industry, such as through the formation of a NEVs industrial park.

The practical significance of the issues discussed in this paper is obvious. The current environmental problems in China are increasingly serious, as they not only hinder economic development, but also significantly decrease people's living standards. Therefore, this study puts forward some specific policy suggestions, as follows.

First, encouraging the development of new energy industries, especially the NEVs industry, will play an important role in improving the quality of the environment and achieving sustainable economic development. As mentioned above, environmental problems, such as polluted air and water, traffic congestion and solid waste build-up, are inescapable during the process of urbanization. China must place greater emphasis on strengthening the energy-intensive sectors' awareness of climate change adaptation, as a long-term goal, with the assistance of city planning (Wang et al., 2012). Technology improvement in the NEVs industry greatly benefits energy saving and emission reduction efforts and will assist in improving the quality of the urbanization process, creating a better life for citizens. During this period while the industry is emerging, governments should introduce more policies to ensure a fair and competitive environment. Building on the Energy Saving and NEV Industry Development Plan (2012–2020) and the Notice on the Financial Support Policy for the Promotion and Application of NEVs (2016–2020) have already been introduced, and such policies should aim to stimulate the innovation of the whole NEVs market, not only large firms.

Second, efforts to further increase government support to promote technological process for the NEVs firms and for all industries will be highly significant. As Zhang et al. (2012) and Wang et al. (2012) noted, in the majority of cases, pollution controls have a negative impact on economic performance. Incentives should be offered and new technological approaches adopted to improve the energy efficiency of the energy-intensive industries, which requires significant government support. It is widely acknowledged that for the emerging industries, especially the NEVs industry, government supporting policies are indispensable. Our practical results prove the rationality of the assumptions made in this study, namely, that both government policies and financial subsidies are beneficial in increasing the efficiency of large NEVs firms. This includes subsidies from state and local governments during the production and promotion of NEVs. For most firms in science parks, financing is the basis of innovation. Internal barriers, especially a lack of money, resources and capability, are the main obstacles to the implementation of clean production and sustainable cooperation. Sufficient government financial subsidies can decrease liquidity risks and promote technical progress. In an emerging industry, the support of government will lay a stable foundation that can assist large firms to grow faster and stronger, enabling them to take advantage of size effects (Almus and Czarnitzki, 2003; Hall and Bagchi-Sen, 2007).

Most importantly, although mergers and acquisitions are encouraged for the expansion of firms, government policies should not only promote the development of large NEVs firms that are already more competitive in the market, but also protect the innovative capabilities of small NEVs firms. In this study, we have found that small firms cannot benefit from the supporting policies offered by governments. The characteristics of the financial demands of small and medium enterprises (SMEs) and their financial supply channels have been analyzed in previous studies. Saunders et al. (2014) considered that financing is difficult for virtually all science and technology SMEs and pointed out that indirect and direct financing channels are narrow, the policy financing channels are not obvious and the credit guarantee systems are incomplete. As Kaoru et al. (2017) explained, the benefits to firms from government policies are likely to depend on firm and industry characteristics, and SMEs with lower productivity require more supporting policies and financial subsidies. Thus, the government should design more SME-friendly policies. Only in this way can the government create a healthy market environment for the future of the NEVs industry, and promote the further development of energy savings and emissions reductions to ensure clean urbanization and sustainable development in China.

5. Conclusions

In this study, firm-level data from the ZGC Science Park are used to explore the influencing factors in the development of the NEVs industry. The determinants of firm efficiency are discussed in detail, especially the influence of firm size in improving the NEVs firms' performance.

The results indicate that government support is more beneficial for large firms that already have abundant resources and are highly competitive than it is for smaller firms. The greater impact of government support on the promotion of efficiency in large firms is evident from their better resource integration and larger market shares. Furthermore, many large firms have excluded small firms, using the support obtained from government policies to form a monopolistic or oligopolistic position, which is harmful to the development of the NEVs industry.

In contrast to the effect on large firms, government policies aiming to support industry can reduce the efficiency of small firms and hinder their development. However, the NEVs industry is an emerging industry that demands more innovation and greater technical breakthroughs, such as the development of safer and more efficient batteries. Therefore, the importance of small firms in this industry has to be recognized. It is suggested that the government should enact and implement supporting policies aimed specifically at the small firms in the NEVs industry to encourage their innovation and technical progress, and to promote the long-term development of the NEVs industry.

There are some shortcomings and limitations of this study, particularly in relation to the sample collection and data availability. First, this study uses the number of patents per firm to calculate the efficiency of a firm. However, the patent protection system is not perfect in some industries, as research results must be made public in the application for a patent, which makes it easier for other firms to imitate the innovation. Thus, some firms may choose not to apply for a patent or to delay their application for a patent. As this study cannot analyze this tendency, it may result in errors in evaluating the innovation efficiency of a firm. Moreover, the internal characteristics of firms, which could not be determined in this study, may have a significant impact on firm efficiency. In future studies, we aim to investigate the internal characteristics of firms in the NEVs industry to further analyze their influence on a firm's technological progress and diffusion process, and to gain more information on their role in the development of NEVs firms.

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