Received: 7 September 2022 | Revised: 22 March 2023 | Accepted: 2 April 2023

DOI: 10.1002/bse.3431

RESEARCH ARTICLE

Business Strategy and the Environment WILEY

China's manufacturing firms' willingness to pay for carbon abatement: A cost perspective

Yunfei An[1] | Xunpeng Shi[2,3] | Qunwei Wang[4,5] | Jian Yu[6] | Dequn Zhou[4,5] | Xiaoyong Zhou[7]

[1]Business School, Henan University, Kaifeng, China

[2]Australia-China Relations Institute, University of Technology Sydney, Ultimo, New South Wales, Australia

[3]Center of Hubei Cooperative Innovation for Emissions Trading System & School of Low Carbon Economics, Hubei University of Economics, Wuhan, China

[4]College of Economics and Management, Nanjing University of Aeronautics and Astronautics, Nanjing, China

[5]Research Centre for Soft Energy Science, Nanjing University of Aeronautics and Astronautics, Nanjing, China

[6]School of Economics, Central University of Finance and Economics (CUFE), Beijing, China

[7]College of Management, Guilin University of Aerospace Technology, Guilin, China

Correspondence
Xunpeng Shi, Center of Hubei Cooperative Innovation for Emissions Trading System & School of Low Carbon Economics, Hubei University of Economics, Wuhan 430205, China.
Email: xunpeng.shi@uts.edu.au

Qunwei Wang, Research Centre for Soft Energy Science, Nanjing University of Aeronautics and Astronautics, 29 Jiangjun Avenue, Nanjing 211106, China.
Email: wqw0305@126.com

Funding information
Philosophy and Social Science Planning Project of Henan Province, Grant/Award Number: 2022CJJ129; Humanities and Social Science General Project in Colleges and Universities of Henan Province, Grant/Award Number: 2023-ZDJH-057; National Natural Science Foundation of China, Grant/Award Numbers: 71834003, 71922013, 72174056, 72064005; Major Program of National Fund of Philosophy and Social Science of China, Grant/Award Number: 21&ZD110; Key Program of Higher University of Henan Province, Grant/Award Number: 23A790009; Natural Science Foundation of Guangxi Province, Grant/Award Number: 2020GXNSFAA159041

Abstract

The existing studies of emissions reduction focus mainly on the technical potential and abatement costs while overlooking firms' willingness to pay (WTP) for emissions reduction. Yet WTP is a key parameter in a firm's decision to carry out emissions reduction while maximizing its profits. This paper estimates China's manufacturing industry (CMI) firms' maximum WTP for carbon abatement—defined as the cumulative product between the marginal abatement cost and corresponding abatement potential—using a large sample from a data envelopment analysis model. The results show that (a) the maximum WTP is significantly constrained by an isocost carbon abatement curve at RMB 8.65 million for the representative CMI firm; (b) the representative firms' WTP for carbon abatement varies among the sub-sectors; and (c) profitability and production scales both positively affect firms' WTP for carbon abatement in all of CMI sub-sectors, while innovation investment has a negative effect. The results suggest that the cost of carbon reduction technology for CMI firms should be below RMB 8.65 million for a representative CMI firm. The government should formulate subsidies or tax relief policies to help firms reduce their abatement costs. Further, the division of tasks in different sub-sectors, between carbon emissions reduction on the one hand, and ongoing innovation on the other, should be clearly distinguished by policy bias to promote the transformation of industrial structure.

Abbreviations: CGE, computable general equilibrium; CMI, China's manufacturing industry; DEA, data envelopment analysis; GS, grid search; ICAC, isocost carbon abatement curve; LEAP, long-range energy alternative planning system; MAC, marginal abatement cost; MACC, marginal abatement cost curve; VRS, variable returns to scale; WTP, willingness to pay.

KEYWORDS
abatement potential, carbon abatement cost, manufacturing industry, marginal abatement cost, willingness to pay

1 | INTRODUCTION

Global warming caused by excessive carbon dioxide emissions is steadily intensifying, causing a series of environmental problems. Many countries have taken action to reduce carbon emissions to alleviate climate deterioration (Zhou et al., 2020). As the largest carbon emitter, China has announced ambitious carbon emissions reduction targets for 2030 and 2060 (Weng et al., 2021).

To achieve carbon emissions reduction targets, China launched a national emissions trading system (ETS) in 2021 (Fang & Cao, 2021). It covers only coal-fired and gas-fired power plants. However, the manufacturing industry, which is China's largest energy-consuming sector (Xu & Lin, 2017), which directly and indirectly emits more than half of the country's carbon emissions, has not yet been covered. When and how to incorporate manufacturing into China's ETS still needs further evaluation (Wang et al., 2023).

Marginal abatement cost (MAC) and emissions abatement potential are often used as two important reference indicators for carbon emissions abatement policy formulation (An & Zhai, 2020; Zhou et al., 2014), but a study of the relationship between the two indicators of China's manufacturing industry (CMI) firms is still lacking. Although the marginal abatement cost curve (MACC) has portrayed this relationship, it is only for an independent, individual firm or region from an abatement technology perspective (Busch et al., 2019). Furthermore, the MAC reflects the cost per unit of carbon abatement, and the abatement potential reflects possible carbon emissions reductions. Estimating any of the two indicators depends on the assumption of the other, and thus presentation of the estimated individual indicator may be misleading. In contrast, the product of the two indicators can be regarded as the total abatement cost, which objectively and realistically reflects the firm's willingness to pay (WTP) for carbon abatement. However, most of the existing studies pertaining to CMI firms' WTP for carbon abatement (WTPCA) focus on technology cost estimation (Bostanci et al., 2018; Krozer, 2013; Pilorgé et al., 2020; Rubin et al., 2012; Rubin & Zhai, 2012) and questionnaire surveys (Liu et al., 2013; Liu & Fan, 2018; Zhao et al., 2018). There is still a gap in the estimation of the maximum WTP of CMI firms from an objective perspective. Furthermore, there are few studies of the MAC at the firm level.

Exploring the manufacturing firms' maximum WTPCA can provide critical information for carbon abatement policy formulation and technology research, development, and deployment. In order to maximize the firms' profits, the decisions they make depend on the costs and benefits. Hence, the total abatement cost is the decisive factor affecting a firm's emissions abatement investment, and thus, the maximum WTP is a hard constraint for the individual firm. This is because most firms are profit-oriented entities that care more about their own earnings (Mazlan et al., 2022). Such information will help policymakers to understand the limit any policy can push. In the research and development process of energy-saving and carbon reduction technologies in the CMI, the overall carbon price can be used as a guide for the cost of the technology. This total cost can also be regarded as the maximum WTPCA.

In this study, using a large firm-level sample, we investigate the overall relationship between the MAC and emissions abatement potential in CMI firms through a data envelopment analysis (DEA)-based model. The carbon abatement costs that the CMI firms are willing to pay are further analyzed by each sub-sector based on the relationship. The drivers that influence the carbon abatement costs between sub-sectors are also analyzed.

The study fills the gaps in the research relating to CMI firms. First, through analyzing the overall distribution characteristics of the MACs and abatement potentials, the abatement cost constraint curve of CMI firms is found and can be considered as the firms' maximum WTPCA. Second, the carbon abatement costs for firms in CMI sub-sectors are estimated, and the drivers causing the heterogeneity among the sub-sectors are clarified. Third, the implications for carbon abatement both from technology development and policy development are drawn.

The remainder of this article is as follows: Section 2 reviews the literature related to this study, Section 3 outlines the model and data, Section 4 presents the results, Section 5 discusses the results, and the final section summarizes the conclusions and policy implications.

2 | LITERATURE REVIEW

Researchers of carbon emissions reduction have devoted considerable attention to the MAC and abatement potential. The MAC refers to the cost of reduction per unit of emissions and is often used as a reference for carbon pricing when formulating abatement policies. Many existing studies have estimated the carbon MAC of China's economic sectors (Lee & Zhang, 2012; Wang & He, 2017; Xiao et al., 2014; Xie et al., 2017). Taking the region as the research object, there are also some studies that have measured the MAC of carbon emissions in Chinese cities, provinces, and even the whole China (Dai et al., 2020; Wang et al., 2017; Wang, Xian, et al., 2020; Xue et al., 2021). However, both technology and policy must be applied to micro-enterprises to further produce macro-level implementation effects. The measurement of the MAC in a macroscopic may be different from the actual MACs of firms (An et al., 2021; Wang & He, 2017). However, only a few studies have used firm-level data (An et al., 2021; Nakaishi, 2021; Wei et al., 2013).

There are several methods available for estimating the MAC. Sjöstrand et al. (2019) estimated the MAC using the expert-based approach. The top-bottom economic model, like the computable general equilibrium (CGE) model, can also be used to measure the marginal abatement for macro individuals (Jiang et al., 2022; Tang et al., 2020; Zhang et al., 2021). The distance function is used to estimate the MAC by calculating the shadow price (An et al., 2021). There are two forms of distance function: parametric and non-parametric. The parametric method is used mainly to measure the MAC by fitting the production function parameters. The quadratic production function is one of the most widely used forms of distance function (Cheng et al., 2019). Many studies have used it to measure the MAC (Ji & Zhou, 2020; Wang, Chen, et al., 2020; Wei et al., 2013). The non-parametric method is the DEA approach. Since the DEA method estimates the direction distance function, the production function form is not selected in advance, and the data requirements are relatively low. Therefore, it is also widely used in the measurement of MAC (An & Zhai, 2020; Kaneko et al., 2010; Lee et al., 2002; Wang & Wei, 2014; Xian et al., 2020).

As an indicator for the guidance of carbon policy, abatement potential has been estimated using a variety of methods from different levels. Abatement potential refers to the potential emissions reduction that an individual firm or geographical area can achieve under the premise of being technically and economically feasible, which can also be regarded as an untapped carbon abatement ability (Yu et al., 2016). It is often used to evaluate the feasibility of emissions reduction targets (Clarke et al., 2016; Tan et al., 2018; Zeng et al., 2020) or to explore a different way to reduce carbon emissions (Wang et al., 2019; Yuan et al., 2019). Similar to the MAC, most studies relating to abatement potential for China are from province-level and city-level perspectives. To measure the carbon abatement potential, Wang et al. (2018) used the learning curve and discovered China's regional carbon abatement potential. Wang et al. (2019) explored the carbon abatement potential of China's provinces using the windows analysis approach. Yuan et al. (2019) calculated the carbon abatement potential of multiproduct pipelines by using a bottom-up framework and a stepwise multiple linear regression. Hu et al. (2019) estimated the carbon reduction potential of the post-industrial city using a long-range energy alternative planning system (LEAP). Zeng et al. (2020) investigated the carbon reduction potential for China's thermal power industry through a two-stage DEA method.

Most of the existing literature relates to the relationship between the MAC and abatement potential. The MAC curve essentially links abatement costs and technology for a firm (McKitrick, 1999), but it is now also applicable to macro-individual areas and sectors. Du et al. (2015) estimated China's provincial MAC curve, and the reduction goal is drawn correspondingly. Wang, Xian, et al. (2020) explored the optimized carbon abatement trajectory for China's petroleum industry by estimating MAC curves. Yue et al. (2020) used the MAC curves to compare the emissions reduction technology options.

The studies about carbon abatement costs that firms are willing to pay are concentrated mainly on technology costs and questionnaire survey aspects. Rubin and Zhai (2012) investigated the cost of carbon capture and storage for natural gas combined cycle power plants. Rubin et al. (2012) evaluated the cost of three forms of carbon capture: post-combustion, pre-combustion, and oxy-combustion capture. Krozer (2013) analyzed the costs and benefits of renewable energy generation. Bostanci et al. (2018) explored the cost of the supplementary cementitious materials that can be added to cement in order to reduce carbon emissions. Pilorgé et al. (2020) assessed carbon capture and storage for the industrial sector. Other studies concentrated on firms' WTPCA. Liu et al. (2013) explored the firms' WTPCA using a multiple-bounded discrete choice format and found that market competition degree and firm size had a significant impact on the WTP. Through a questionnaire survey, Zhao et al. (2018) found that emissions trading schemes in China could increase firms' WTPCA by 7%. Liu and Fan (2018) investigated 105 firms in cement sub-sectors, and found that the WTP for emissions abatement would be RMB 90/t-CO_2 by 2030.

In summary, there are two notable gaps in the literature. First, the research on the MAC and reduction potential is focused mostly on the macro perspective. Although the microscopic MAC measurement is closer to the true value (An et al., 2021), there are few studies that concentrate on the firm level, especially for manufacturing firms. Second, while the MAC curve can reflect the relationship between the MAC and abatement potential, it usually reflects the characteristics of an individual firm. The overall distribution relationship between the two indicators of firms has not been described. The existing literature on firms' WTPCA is concentrated mainly on specific emissions reduction technologies and questionnaire surveys which do not actually reflect the real carbon abatement cost that firms are willing to pay due to the lack of practicality or the existence of subjectivity.

3 | METHODOLOGY AND DATA

3.1 | Model

The model in this section was designed to measure the MAC and abatement potential of China's manufacturing firms based on the DEA method. We define manufacturing firm j as DMU$_j$, $j = 1,2,\cdots,N$. In the period t, the j_nth manufacturing firm's inputs fixed assets cost $k_{j_n}^t$, labor cost $l_{j_n}^t$, materials cost $c_{j_n}^t$, and energy cost $e_{j_n}^t$ to produce desired output revenue $y_{j_n}^t$. The production process is accompanied by carbon emissions which are an undesirable output $b_{j_n}^t$ (Shi et al., 2020). In a short period T ($T = 1,2,\cdots,t$), the DMU$_{j_n}$'s production technology $TE_{j_n}^t$ can be defined as formula (1).

$$TE_{j_n}^t = \left\{ \left(k_{j_n}^t, l_{j_n}^t, c_{j_n}^t, e_{j_n}^t, y_{j_n}^t, b_{j_n}^t\right) | \begin{array}{l} \sum_{T=1}^{t} \lambda_{j_n}^T k_{j_n}^T \le k_{j_n}^t, \sum_{T=1}^{t} \lambda_{j_n}^T l_{j_n}^T \le l_{j_n}^t, \sum_{T=1}^{t} \lambda_{j_n}^T c_{j_n}^T \le c_{j_n}^t, \sum_{T=1}^{t} \lambda_{j_n}^T e_{j_n}^T \le e_{j_n}^t, \\ \sum_{T=1}^{t} \lambda_{j_n}^T y_{j_n}^T \ge y_{j_n}^t, \sum_{T=1}^{t} \lambda_{j_n}^T b_{j_n}^T \le b_{j_n}^t, \sum_{T=1}^{t} \lambda_{j_n}^T = 1 \end{array} \right\}, \tag{1}$$

where vector $\lambda_{j_n}^T$ denotes the weight combination of the production technology for the years, $\lambda \in R_n^+$. Considering that both production and emissions reduction have scale effects, we assume that the model has variable returns to scale (VRS), that is, $\sum_{T=1}^{t} \lambda_{j_n}^T = 1$. Both the production and carbon emissions of the DMU$_{j_n}$ are constrained by formula (1) due to the technology limitation.

Generally, manufacturing firms' production is aimed at either its minimizing cost or maximizing profit. To calculate the MAC instead of reducing output from technological advancement and reducing the desirable output, we assume that the DMU_{j_n} in the model performs production based on orders $y^*_{j_n}$. That means the DMU_{j_n} seeks a weight combination of the production technology $\lambda^T_{j_n}$ to make its cost optimized under the premise of achieving the desirable output $y^*_{j_n}$. Then, the decision function for DMU_{j_n} can be expressed as model (2).

$$\min \overline{l^t_{j_n}} + \overline{c^t_{j_n}} + \overline{e^t_{j_n}} + \overline{k^t_{j_n}} + \tau_i \overline{b^t_{j_n}}$$
$$\text{s.t.} \begin{cases} \sum_{T=1}^{t} \lambda^T_{j_n} k^T_{j_n} \le \overline{k^t_{j_n}} \\ \sum_{T=1}^{t} \lambda^T_{j_n} l^T_{j_n} \le \overline{l^t_{j_n}} \\ \sum_{T=1}^{t} \lambda^T_{j_n} c^T_{j_n} \le \overline{c^t_{j_n}} \\ \sum_{T=1}^{t} \lambda^T_{j_n} e^T_{j_n} \le \overline{e^t_{j_n}} \\ \sum_{T=1}^{t} \lambda^T_{j_n} y^T_{j_n} \ge y^*_{j_n} \\ \sum_{T=1}^{t} \lambda^T_{j_n} b^T_{j_n} \le \overline{b^t_{j_n}} \\ \sum_{T=1}^{t} \lambda^T_{j_n} = 1 \\ \lambda^T_{j_n} \ge 0 \end{cases}, \tag{2}$$

where the τ_i is the unit carbon price formulated by carbon policy, $\tau_i > 0$, $\tau_i \in \mathrm{R}$.

The DMU_{j_n} will realize the carbon abatement potential when the carbon price τ_i is larger than its MAC_{j_n}. Therefore, the MAC_{j_n} can be solved by the search method according to the method by An et al. (2021). We define two carbon prices τ_m and τ_n, $\tau_m < \tau_n$. If τ_n-$\tau_m < a$ and $\overline{b^t_{j_n n}} - \overline{b^t_{j_n m}} < 0$ hold for every positive real number a, we obtain $MAC_{j_n} = \tau_n$. The corresponding abatement potential $\Delta \overline{b^t_{j_n}}$ is $\overline{b^t_{j_n m}} - \overline{b^t_{j_n n}}$ where the $\overline{b^t_{j_n m}}$ and $\overline{b^t_{j_n n}}$ are the optimal solutions for model (2) when the carbon prices are τ_m and τ_n, respectively. To achieve the above calculations, we used grid search (GS) as the solution method; the τ_n-τ_m is the search step.

3.2 | Data description

The data used in this study were based on a 50% sample of the Chinese tax database. Based on the availability, the data are from 2008 to 2011. While the data are a decade old, it has several advantages over the prevailing firm-level data. Compared with the listed firms' data that have often been used for emission studies, our data have a large sample size and cover every sub-sector of CMI. In contrast, there are only less than 3000 listed firms in China. Compared with another large sample data, China Industrial Economic Survey Data, the major advantage of our data is the availability of energy consumption data, which is essential to calculate emissions. Our data have been used in recent publications, such as Wang et al. (2022, 2023).

Considering the representativeness of the study, we further extracted firms with stable operating data. Firms with unstable operating data (including operating employees, output value, and energy input) were excluded from the sample data. The carbon emissions of firms were calculated according to the Intergovernmental Panel on Climate Change (IPCC, 1995) method. The production of firms based on orders are represented by the average of their own output values. The search step is set at RMB 10/ton when solving the model (2) using the GS method.

4 | RESULTS

4.1 | Constraint curve of CMI firms' WTPCA

Based on the model and data in Section 3, the overall results are drawn in Figure 1, including the MAC and abatement potential for CMI firms' carbon reduction. It shows the relationship between the abatement potential and corresponding MAC. Each point shows how a firm would reduce its carbon emissions and realize the corresponding abatement potential when the carbon price formulated by a particular policy is higher than its MAC.

In Figure 1, the distribution of most of the points is obviously close to the coordinate axis, which can be enveloped approximately by an inverse function curve, as formula (3).

$$MAC = \eta / \Delta \overline{b}. \tag{3}$$

As the product of the MAC and abatement potential is the total carbon abatement cost, the envelope curve we added can be regarded as an isocost carbon abatement curve (ICAC). The parameter η denotes the constraint of the carbon emissions abatement cost, which can be expressed as the total investment necessary for most of CMI firms in order to reduce carbon emissions provided it does not exceed this value. As such, the ICAC can be regarded as a cost constraint on the overall WTPCA of CMI firms, and the parameter η is the constraint of the payment.

The ICAC in Figure 1 indicates that no less than 95% of the points must fall within the space enclosed by the coordinate axis and the

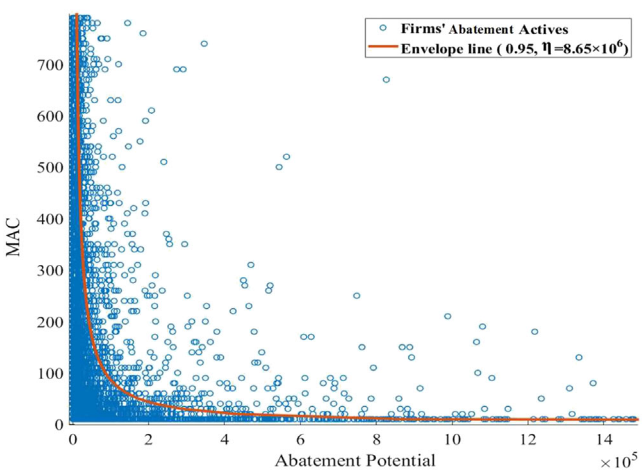

FIGURE 1 The distribution of the CO_2 MAC and its corresponding abatement potential for China's manufacturing firms.

curve. Then, the parameter of the ICAC, $\eta = 8.65 \times 10^6$, means that the most of CMI firms' WTPCA does not exceed RMB 8.65 million.

4.2 | CMI sub-sectors' maximum WTPCA

Further, we found that the distribution of the CO_2 MACs and the corresponding abatement potential for manufacturing firms in each sub-sector are similar to those in Figure 1. This means that there is an upper bound on the WTPCA in each CMI sub-sector. However, CMI firms in different sub-sectors have diverse production and operation characteristics which may lead to different WTP. To explore the differences between each sub-sector, we further classified the calculation results into 31 sub-sectors (see Appendix A) according to the "industrial classification for national economic activities" (National Bureau of Statistics of China [NBS], 2017). The ICACs that envelope 95% of the firms' carbon abatement costs in each sub-sector can be estimated in order to determine firms' WTPCA. The carbon abatement cost constraint for each of China's manufacturing sub-sectors is shown in Figure 2.

In Figure 2, the firms' WTPCA in nine manufacturing sub-sectors (C16, C22, C25, C26, C28, C30, C31, C32, and C36) is above that for China's manufacturing firms overall. Most of these nine sub-sectors belong to heavy industry, with only three belonging to light industry. The firms willing to pay high abatement costs are concentrated mostly in mineral resource processing industries, such as the fuel, metallic, and non-metallic industries. Firms in chemical and fiber processing are also willing to pay higher abatement costs while the high-tech industry firms are generally not willing to pay higher abatement costs.

Firms in the tobacco processing sub-sectors (C16) pay far more than other sub-sectors in emissions abatement costs. This is related to the unique policies of the Chinese government. In China, as tobacco processing sub-sectors are monopolized by the government (Yang et al., 2015), tobacco processing firms have a different market mechanism from other sub-sectors which enables them to have higher profits and higher taxes (Hu et al., 2006). As a result, tobacco processing firms are willing to pay more for carbon emissions abatement than other CMI firms.

4.3 | Heterogeneity of the maximum WTPCA

Firms in different sub-sectors differ in their WTPCA. To determine what causes the differences among the sub-sector firms, we analyzed the influencing indicators from six aspects referencing related studies, including energy mix, profitability, innovation investment, labor scale, production scale, and undesirable outputs scale (He et al., 2022; Parry & Williams, 1999; Wright & Nyberg, 2017; Yao et al., 2018). Energy mix reflects the proportion of electricity, which affects the firm's carbon emission and energy transition; innovation investment demonstrates the firm's creative ability, which can reveal the technical level of the production; profitability, labor scale, production scale, and undesirable outputs scale reflect the basic situation of the firm's operation. All these six factors are directly or indirectly related to carbon emissions, affecting the WTP. To express these, we used the average proportion of electric energy (PEE), average net profit (NP), average R&D expenditure (RD), average number of employees (NE), average total output value (TOV), and average total carbon emissions (TCE). The regression model for influencing indicators of WTPCA can be expressed as formula (4).

$$WTPCA = cons + \beta_1 PEE + \beta_2 NP + \beta_3 RD + \beta_4 NE + \beta_5 TOV + \beta_6 TCE + \varepsilon, \quad (4)$$

where β_1, β_2, β_3, …, β_6 represent the coefficients to be estimated in the multiple regression; *cons* denotes constant; and ε denotes random error. Table 1 shows the regression results of the indicators that affect CMI firms' WTPCA. These results are based on formula (4) and the sample data.

From Table 1, it can be seen that both the *F* and R^2 values are high, indicating that the model is highly significant. The RD and TOV variables are significant with respect to the model at the 5% level, and

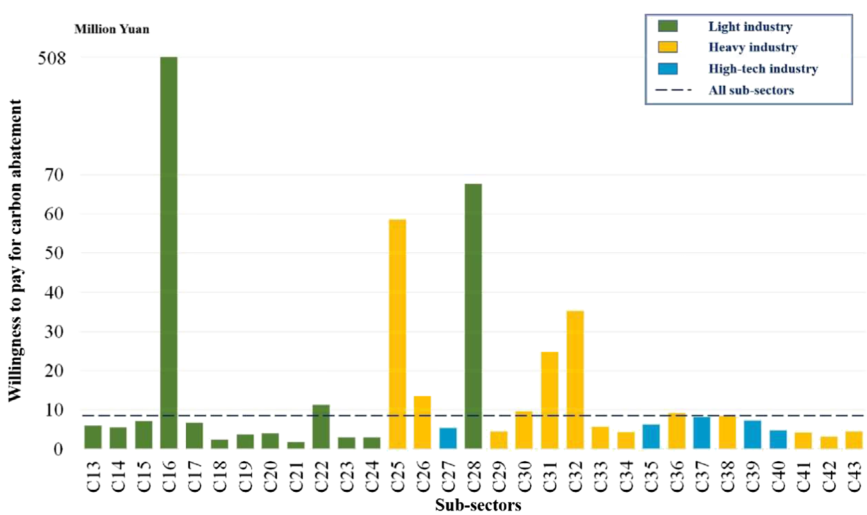

FIGURE 2 Firms' WTP for carbon abatement in each CMI sub-sector.

TABLE 1 The impact of indicators on CMI firms' WTP for carbon abatement.

Variables	Coefficients	t	P
PEE	−0.0188062	−0.57	.574
NP	0.8868738	4.78	.000***
RD	−0.3960958	−2.39	.025**
NE	0.0628238	0.71	.485
TOV	0.4565219	2.73	.012**
TCE	0.0248088	0.54	.591
$F(6, 24)$	239.74		
R^2	.9836		

*Statistical significance at the 10% level.
**Statistical significance at the 5% level.
***Statistical significance at the 1% level.

the NP variable is significant with respect to the model at the 1% level. The variables PEE, NE, and TCE are not significant.

Hence, the indicators that significantly affect the firms' WTPCA in each manufacturing sub-sector are profitability, innovation investment, and production scale. The coefficients of NP and TOV are 0.8868738 and 0.4565219, respectively, and mean that profitability and production scale can promote firms' WTPCA in the CMI sub-sectors. On the contrary, the coefficient of RD is −0.3960958, which means that innovation investment has a negative effect on the WTPCA. Therefore, the main factors accounting for the difference in firms' WTPCA between different sub-sectors are profitability, innovation investment, and production scale.

5 | DISCUSSION

The results reveal the distributional characteristics of the overall MACs of CMI firms and the corresponding abatement potential. Most of the carbon abatement activities of the firms can be approximately enveloped by a space. The main reason for this phenomenon is the non-negativity of the MAC and emissions abatement potential and the constraint of the total cost of carbon emissions abatement that the firms can accept.

This study reveals the relationship between the MAC and the abatement potential in the same coordinate system. Although our WTP concept differs from the MAC curve, they are not inconsistent. The MACC focuses mainly on the relationship between the individual firm's MAC and its total emissions abatement potential, reflecting the fact that unit carbon abatement costs are affected by changes in reduction scale from a technology perspective (Davis et al., 2023). This study differs from other studies on MAC and abatement potential in that it analyzes the overall carbon abatement characteristics of multiple individuals over a period of time from a macro perspective and focuses on the distributional relationship between the MACs and the emissions abatement potentials under a certain technological level.

The results show that the representative firm is not willing to pay for abatement activities which exceed RMB 8.65 million per year. A new carbon reduction technology may not be widely accepted by China's manufacturing firms if the annual cost of the technology exceeds RMB 8.65 million for the representative firm. Previous studies also confirm that the abatement expenditure of RMB 8.65 million per year is still unacceptable to many firms (95% of the total firms). For example, according to the survey by Zhao et al. (2018), nearly one third of CMI firms are willing to pay more than RMB 1 million per year for carbon abatement during the “Twelfth Five-Year Plan” period (from 2011 to 2015), which is close to our results. This means that the WTPCA of RMB 1 million per year is more prevalent among CMI firms.

Firms' maximum WTPCA differs among the sub-sectors. The distribution of firms in different CMI sub-sectors has a similar pattern to that of the overall distribution, but the difference is that the ICACs for different sub-sectors vary. Firms in mineral resource processing industries, such as fuel, metallic, and non-metallic, and chemical and fiber processing and manufacturing are more willing to pay more for carbon emissions abatement. Firms in the cigarette and paper sub-sectors are also willing to invest more in carbon emissions abatement. But in the high-tech sub-sector, the WTPCA is less than that in the other sub-sectors. This result is relatively close to the result obtained by Zhao et al. (2018) through a questionnaire survey. But the sample in our study covers all manufacturing sub-sectors rather than seven sub-sectors in Zhao et al. (2018), making a more comprehensive and objective result. The sub-sectors that are willing to invest more in carbon abatement should receive more attention in carbon reduction technology research and development. The government can also use policies to further stimulate firms to invest more in energy conservation and emissions abatement (Nemet et al., 2017).

Profitability, innovation investment, and production scale have a significant impact on sub-sector firms' WTP. The scales of production and profits are positively correlated with firms' emissions abatement costs. Firms in sub-sectors that operate at a larger scale have stronger risk resistance capabilities (Neise & Diez, 2019) and thus have high WTP. Their large profits can guarantee sufficient funds for carbon emissions abatement investments (Lantz & Sahut, 2005).

By contrast, investing more in innovation will reduce the firms' carbon emissions abatement investment (Blyth et al., 2009). This means that when a firm's financial resources are limited, more investment in innovation means less investment in carbon emissions abatement. Firms with more investment in innovation, especially firms in the high-tech sub-sectors, generally have higher energy efficiencies, and the need for carbon emissions abatement is limited (Lin & Yang, 2013). Moreover, the carbon intensity of high-tech firms is less than that of other CMI firms (Wei et al., 2019). These homogeneities suggest that a discriminatory carbon abatement policy could be more helpful in industrial transformation and promotion of sustainable development of CMI (An et al., 2022). For traditional manufacturing industries, a strict carbon emissions abatement policy should be used to stimulate carbon abatement. For firms in high-tech sub-sectors, a less stringent carbon emissions abatement policy should be formulated to reduce their carbon abatement burden and to support them in creating more value.

6 | CONCLUSIONS

As China is in the process of developing climate change mitigation policies, and given that CMI accounts for the lion's share of China's total emissions, exploring CMI firms' WTPCA can provide critical information specifically for carbon abatement policy formulation and technology research, development and deployment. This study explores CMI firms' maximum WTPCA by analyzing the relationship between the MAC and abatement potential using the DEA and GS methods. The drivers influencing the WTP of CMI firms in different sub-sectors are analyzed. The conclusions and policy implications can be summarized as follows.

The carbon abatement activities of CMI are constrained by the total abatement cost. The analyses suggest that CMI firms will reduce their carbon emissions within the different MACs and abatement potentials, but the costs of carbon abatement, which can be seen as the maximum of firms' WTP, do not exceed RMB 8.65 million for the representative firm. Additionally, firms' WTPCA in different manufacturing sub-sectors varies. The firms in sub-sectors, which are related to the processing of fuels, mining processing, chemicals, paper, and tobacco, are willing to pay more for carbon abatement. These industries fall mostly into the heavy industry category. By contrast, the firms in the high-tech sub-sectors are willing to pay less for carbon abatement. Furthermore, profitability and production scales have a positive effect on firms' WTPCA, while innovation investment has a negative effect.

Based on the above findings, the following policies should be considered. First, the Chinese government can reduce costs through subsidies and tax incentives for firms to invest in new carbon reduction technology. When applying a new carbon reduction technology, the government should evaluate the prospects and costs. From the perspective of a technology developer, the constraint can be used as a benchmark for the feasibility of new abatement technology development. Policies, such as subsidies or tax relief, can support firms developing technologies whose costs do not exceed the cost constraint curve. For firms with significant investments in innovation, the Chinese government should encourage them to maintain these by tax exemption policy while reducing the amounts they pay for carbon abatement.

Second, the Chinese government could set up a discriminatory carbon emissions abatement policy among the CMI sub-sectors, a policy that has been previously proposed (Zhang et al., 2022). CMI's carbon abatement and innovation strategies should be kept separate by a discriminatory carbon abatement policy. Firms with large production scales and good performance should become the leaders in social carbon abatement. Special policies should be formulated to encourage them to invest in carbon abatement. The Chinese government could implement a carbon tax or carbon trading system to encourage and support these sub-sectors' investment in carbon abatement to promote the progress of carbon reduction technologies. Differently, for high-tech firms with more investment in innovation, the government should reduce their emission costs to ensure sufficient innovation funding by the policy.

There are a few limitations with this study that provide directions for future studies. First, it only examines the firms' WTPCA in China based on the cost perspective and does not take into account other factors, such as social responsibilities, that could potentially affect the firms' WTP. Second, the study is based on data from 2008 to 2011 due to data availability. Although the large sample size increases the robustness of the results, the estimation could be improved by using more recent data. Despite these limitations, the results of the study are highly consistent with reality and the literature, which can provide some valuable insights for policymaking.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support from the Philosophy and Social Science Planning Project of Henan Province (2022CJJ129), the Humanities and Social Science General Project in Colleges and Universities of Henan Province (2023-ZDJH-057), the National Natural Science Foundation of China (71834003, 71922013, 72174056, and 72064005), the Major Program of National Fund of Philosophy and Social Science of China (21&ZD110), the Key Program of Higher University of Henan Province (23A790009), and the Natural Science Foundation of Guangxi Province (2020GXNSFAA159041). Open access publishing facilitated by University of Technology Sydney, as part of the Wiley - University of Technology Sydney agreement via the Council of Australian University Librarians.

ORCID

Yunfei An https://orcid.org/0000-0001-6381-9345
Xunpeng Shi https://orcid.org/0000-0001-9653-7395

REFERENCES

An, Y., & Zhai, X. (2020). SVR-DEA model of carbon tax pricing for China's thermal power industry. *Science of the Total Environment*, *734*, 139438. https://doi.org/10.1016/j.scitotenv.2020.139438

An, Y., Zhou, D., Wang, Q., Shi, X., & Taghizadeh-Hesary, F. (2022). Mitigating size bias for carbon pricing in small Asia-Pacific countries: Increasing block carbon tax. *Energy Policy*, *161*, 112771. https://doi.org/10.1016/j.enpol.2021.112771

An, Y., Zhou, D., Yu, J., Shi, X., & Wang, Q. (2021). Carbon emission reduction characteristics for China's manufacturing firms: Implications for formulating carbon policies. *Journal of Environmental Management*, *284*, 112055. https://doi.org/10.1016/j.jenvman.2021.112055

Blyth, W., Bunn, D., Kettunen, J., & Wilson, T. (2009). Policy interactions, risk and price formation in carbon markets. *Energy Policy*, *37*(12), 5192–5207. https://doi.org/10.1016/j.enpol.2009.07.042

Bostanci, S. C., Limbachiya, M., & Kew, H. (2018). Use of recycled aggregates for low carbon and cost effective concrete construction. *Journal of Cleaner Production*, *189*, 176–196. https://doi.org/10.1016/j.jclepro.2018.04.090

Busch, J., Engelmann, J., Cook-Patton, S. C., Griscom, B. W., Kroeger, T., Possingham, H., & Shyamsundar, P. (2019). Potential for low-cost carbon dioxide removal through tropical reforestation. *Nature Climate Change*, *9*(6), 463–466. https://doi.org/10.1038/s41558-019-0485-x

Cheng, S., Lu, K., Liu, W., & Xiao, D. (2019). Efficiency and marginal abatement cost of PM2. 5 in China: A parametric approach. *Journal of Cleaner Production*, *235*, 57–68. https://doi.org/10.1016/j.jclepro.2019.06.281

Clarke, L., McFarland, J., Octaviano, C., van Ruijven, B., Beach, R., Daenzer, K., Herreras Martínez, S., Lucena, A. F. P., Kitous, A., Labriet, M., Loboguerrero Rodriguez, A. M., Mundra, A., & van der Zwaan, B. (2016). Long-term abatement potential and current policy trajectories in Latin American countries. *Energy Economics*, *56*, 513–525. https://doi.org/10.1016/j.eneco.2016.01.011

Dai, S., Zhou, X., & Kuosmanen, T. (2020). Forward-looking assessment of the GHG abatement cost: Application to China. *Energy Economics*, *88*, 104758. https://doi.org/10.1016/j.eneco.2020.104758

Davis, M., Okunlola, A., Di Lullo, G., Giwa, T., & Kumar, A. (2023). Greenhouse gas reduction potential and cost-effectiveness of economy-wide hydrogen-natural gas blending for energy end uses. *Renewable and Sustainable Energy Reviews*, *171*, 112962. https://doi.org/10.1016/j.rser.2022.112962

Du, L., Hanley, A., & Wei, C. (2015). Estimating the marginal abatement cost curve of CO_2 emissions in China: Provincial panel data analysis. *Energy Economics*, *48*, 217–229. https://doi.org/10.1016/j.eneco.2015.01.007

Fang, S., & Cao, G. (2021). Modelling extreme risks for carbon emission allowances—Evidence from European and Chinese carbon markets. *Journal of Cleaner Production*, *316*, 128023. https://doi.org/10.1016/j.jclepro.2021.128023

He, R., Luo, L., Shamsuddin, A., & Tang, Q. (2022). The value relevance of corporate investment in carbon abatement: The influence of National Climate Policy. *European Accounting Review*, *31*(5), 1233–1261.

Hu, G., Ma, X., & Ji, J. (2019). Scenarios and policies for sustainable urban energy development based on LEAP model—A case study of a postindustrial city: Shenzhen China. *Applied Energy*, *238*, 876–886. https://doi.org/10.1016/j.apenergy.2019.01.162

Hu, T. W., Mao, Z., Ong, M., Tong, E., Tao, M., Jiang, H., Hammond, K., Smith, K. R., de Beyer, J., & Yurekli, A. (2006). China at the crossroads: the economics of tobacco and health. *Tobacco Control*, *15*(suppl_1), i37–i41. https://doi.org/10.1136/tc.2005.014621

Intergovernmental Panel on Climate Change. (1995). *Greenhouse gas inventory: IPCC guidelines for national greenhouse gas inventories*. United Kingdom Meteorological Office.

Ji, D. J., & Zhou, P. (2020). Marginal abatement cost, air pollution and economic growth: Evidence from Chinese cities. *Energy Economics*, *86*, 104658. https://doi.org/10.1016/j.eneco.2019.104658

Jiang, H. D., Xue, M. M., Dong, K. Y., & Liang, Q. M. (2022). How will natural gas market reforms affect carbon marginal abatement costs? Evidence from China. *Economic Systems Research*, *34*(2), 129–150.

Kaneko, S., Fujii, H., Sawazu, N., & Fujikura, R. (2010). Financial allocation strategy for the regional pollution abatement cost of reducing sulfur dioxide emissions in the thermal power sector in China. *Energy Policy*, *38*(5), 2131–2141. https://doi.org/10.1016/j.enpol.2009.06.005

Krozer, Y. (2013). Cost and benefit of renewable energy in the European Union. *Renewable Energy*, *50*, 68–73. https://doi.org/10.1016/j.renene.2012.06.014

Lantz, J. S., & Sahut, J. M. (2005). R&D investment and the financial performance of technological firms. *International Journal of Business*, *10*(3), 251.

Lee, J. D., Park, J. B., & Kim, T. Y. (2002). Estimation of the shadow prices of pollutants with production/environment inefficiency taken into account: a nonparametric directional distance function approach. *Journal of Environmental Management*, *64*(4), 365–375. https://doi.org/10.1006/jema.2001.0480

Lee, M., & Zhang, N. (2012). Technical efficiency, shadow price of carbon dioxide emissions, and substitutability for energy in the Chinese manufacturing industries. *Energy Economics*, *34*(5), 1492–1497. https://doi.org/10.1016/j.eneco.2012.06.023

Lin, B., & Yang, L. (2013). The potential estimation and factor analysis of China's energy conservation on thermal power industry. *Energy Policy*, *62*, 354–362. https://doi.org/10.1016/j.enpol.2013.07.079

Liu, X., & Fan, Y. (2018). Business perspective to the national greenhouse gases emissions trading scheme: A survey of cement companies in China. *Energy Policy*, *112*, 141–151. https://doi.org/10.1016/j.enpol.2017.10.019

Liu, X., Niu, D., Bao, C., Suk, S., & Sudo, K. (2013). Affordability of energy cost increases for companies due to market-based climate policies: A survey in Taicang, China. *Applied Energy*, *102*, 1464–1476. https://doi.org/10.1016/j.apenergy.2012.09.008

Mazlan, N. A. S., Nawawi, M. N., Saputra, J., Muhamad, S. B., & Abdullah, R. (2022). Classification of attributes on green manufacturing practices: A systematic review. *Planning*, *17*(6), 1839–1847. https://doi.org/10.18280/ijsdp.170618

McKitrick, R. (1999). A derivation of the marginal abatement cost curve. *Journal of Environmental Economics and Management*, *37*(3), 306–314. https://doi.org/10.1006/jeem.1999.1065

Nakaishi, T. (2021). Developing effective CO_2 and SO_2 mitigation strategy based on marginal abatement costs of coal-fired power plants in China. *Applied Energy*, *294*, 116978. https://doi.org/10.1016/j.apenergy.2021.116978

National Bureau of Statistics of China. (2017). Industrial classification for National Economic Activities (GB/T 4754-2017). http://www.stats.gov.cn/tjsj/tjbz/hyflbz/201710/P020180402592793000880.pdf

Neise, T., & Diez, J. R. (2019). Adapt, move or surrender? Manufacturing firms' routines and dynamic capabilities on flood risk reduction in coastal cities of Indonesia. *International Journal of Disaster Risk Reduction*, *33*, 332–342. https://doi.org/10.1016/j.ijdrr.2018.10.018

Nemet, G. F., Jakob, M., Steckel, J. C., & Edenhofer, O. (2017). Addressing policy credibility problems for low-carbon investment. *Global Environmental Change*, *42*, 47–57. https://doi.org/10.1016/j.gloenvcha.2016.12.004

Parry, I. W., & Williams, R. C. III (1999). A second-best evaluation of eight policy instruments to reduce carbon emissions. *Resource and Energy Economics*, *21*(3–4), 347–373. https://doi.org/10.1016/S0928-7655(99)00008-1

Pilorgé, H., McQueen, N., Maynard, D., Psarras, P., He, J., Rufael, T., & Wilcox, J. (2020). Cost analysis of carbon capture and sequestration of process emissions from the US industrial sector. *Environmental Science & Technology*, *54*(12), 7524–7532. https://doi.org/10.1021/acs.est.9b07930

Rubin, E. S., Mantripragada, H., Marks, A., Versteeg, P., & Kitchin, J. (2012). The outlook for improved carbon capture technology. *Progress in Energy and Combustion Science*, *38*(5), 630–671. https://doi.org/10.1016/j.pecs.2012.03.003

Rubin, E. S., & Zhai, H. (2012). The cost of carbon capture and storage for natural gas combined cycle power plants. *Environmental Science & Technology*, *46*(6), 3076–3084. https://doi.org/10.1021/es204514f

Shi, X., Wang, K., Shen, Y., Sheng, Y., & Zhang, Y. (2020). A permit trading scheme for facilitating energy transition: A case study of coal capacity control in China. *Journal of Cleaner Production*, *256*, 120472. https://doi.org/10.1016/j.jclepro.2020.120472

Sjöstrand, K., Lindhe, A., Söderqvist, T., Dahlqvist, P., & Rosén, L. (2019). Marginal abatement cost curves for water scarcity mitigation under uncertainty. *Water Resources Management*, *33*(12), 4335–4349. https://doi.org/10.1007/s11269-019-02376-8

Tan, X., Lai, H., Gu, B., Zeng, Y., & Li, H. (2018). Carbon emission and abatement potential outlook in China's building sector through 2050. *Energy Policy*, *118*, 429–439. https://doi.org/10.1016/j.enpol.2018.03.072

Tang, B. J., Ji, C. J., Hu, Y. J., Tan, J. X., & Wang, X. Y. (2020). Optimal carbon allowance price in China's carbon emission trading system: Perspective from the multi-sectoral marginal abatement cost. *Journal of Cleaner Production*, *253*, 119945. https://doi.org/10.1016/j.jclepro.2019.119945

Wang, D., Mao, J., Cui, R., Yu, J., & Shi, X. (2022). Impact of inter-provincial power resource allocation on enterprise production behavior from a multi-scale correlation perspective. *Energy Economics*, *114*, 106323. https://doi.org/10.1016/j.eneco.2022.106323

Wang, J., Lv, K., Bian, Y., & Cheng, Y. (2017). Energy efficiency and marginal carbon dioxide emission abatement cost in urban China. *Energy Policy*, *105*, 246–255. https://doi.org/10.1016/j.enpol.2017.02.039

Wang, K., Wang, Z., Xian, Y., Shi, X., Yu, J., Feng, K., Hubacek, K., & Wei, Y. M. (2023). Optimizing the rolling out plan of China's carbon market. *iScience*, *26*(1), 105823. https://doi.org/10.1016/j.isci.2022.105823

Wang, K., & Wei, Y. M. (2014). China's regional industrial energy efficiency and carbon emissions abatement costs. *Applied Energy*, *130*, 617–631. https://doi.org/10.1016/j.apenergy.2014.03.010

Wang, K., Wu, M., Sun, Y., Shi, X., Sun, A., & Zhang, P. (2019). Resource abundance, industrial structure, and regional carbon emissions efficiency in China. *Resources Policy*, *60*, 203–214. https://doi.org/10.1016/j.resourpol.2019.01.001

Wang, K., Xian, Y., Yang, K., Shi, X., Wei, Y. M., & Huang, Z. (2020). The marginal abatement cost curve and optimized abatement trajectory of CO_2 emissions from China's petroleum industry. *Regional Environmental Change*, *20*(4), 1–13. https://doi.org/10.1007/s10113-020-01709-3

Wang, W., Yu, B., Yao, X., Niu, T., & Zhang, C. (2018). Can technological learning significantly reduce industrial air pollutants intensity in China?—Based on a multi-factor environmental learning curve. *Journal of Cleaner Production*, *185*, 137–147. https://doi.org/10.1016/j.jclepro.2018.03.028

Wang, Z., Chen, H., Huo, R., Wang, B., & Zhang, B. (2020). Marginal abatement cost under the constraint of carbon emission reduction targets: An empirical analysis for different regions in China. *Journal of Cleaner Production*, *249*, 119362. https://doi.org/10.1016/j.jclepro.2019.119362

Wang, Z., & He, W. (2017). CO_2 emissions efficiency and marginal abatement costs of the regional transportation sectors in China. *Transportation Research Part D: Transport and Environment*, *50*, 83–97. https://doi.org/10.1016/j.trd.2016.10.004

Wei, C., Löschel, A., & Liu, B. (2013). An empirical analysis of the CO_2 shadow price in Chinese thermal power enterprises. *Energy Economics*, *40*, 22–31. https://doi.org/10.1016/j.eneco.2013.05.018

Wei, Z., Han, B., Han, L., & Shi, Y. (2019). Factor substitution, diversified sources on biased technological progress and decomposition of energy intensity in China's high-tech industry. *Journal of Cleaner Production*, *231*, 87–97. https://doi.org/10.1016/j.jclepro.2019.05.223

Weng, Y., Cai, W., & Wang, C. (2021). Evaluating the use of BECCS and afforestation under China's carbon-neutral target for 2060. *Applied Energy*, *299*, 117263. https://doi.org/10.1016/j.apenergy.2021.117263

Wright, C., & Nyberg, D. (2017). An inconvenient truth: How organizations translate climate change into business as usual. *Academy of Management Journal*, *60*(5), 1633–1661. https://doi.org/10.5465/amj.2015.0718

Xian, Y., Wang, K., Wei, Y. M., & Huang, Z. (2020). Opportunity and marginal abatement cost savings from China's pilot carbon emissions permit trading system: simulating evidence from the industrial sectors. *Journal of Environmental Management*, *271*, 110975. https://doi.org/10.1016/j.jenvman.2020.110975

Xiao, H., Wei, Q., & Wang, H. (2014). Marginal abatement cost and carbon reduction potential outlook of key energy efficiency technologies in China's building sector to 2030. *Energy Policy*, *69*, 92–105. https://doi.org/10.1016/j.enpol.2014.02.021

Xie, B. C., Duan, N., & Wang, Y. S. (2017). Environmental efficiency and abatement cost of China's industrial sectors based on a three-stage data envelopment analysis. *Journal of Cleaner Production*, *153*, 626–636. https://doi.org/10.1016/j.jclepro.2016.12.100

Xu, R., & Lin, B. (2017). Why are there large regional differences in CO_2 emissions? Evidence from China's manufacturing industry. *Journal of Cleaner Production*, *140*, 1330–1343. https://doi.org/10.1016/j.jclepro.2016.10.019

Xue, Z., Li, N., Mu, H., Zhang, M., & Pang, J. (2021). Convergence analysis of regional marginal abatement cost of carbon dioxide in China based on spatial panel data models. *Environmental Science and Pollution Research*, *28*, 1–18. https://doi.org/10.1007/s11356-021-13288-9

Yang, T., Barnett, R., Rockett, I. R., Yang, X. Y., Wu, D., Zheng, W., & Li, L. (2015). The impact of regional economic reliance on the tobacco industry on current smoking in China. *Health & Place*, *33*, 159–171. https://doi.org/10.1016/j.healthplace.2014.12.015

Yao, X., Kou, D., Shao, S., Li, X., Wang, W., & Zhang, C. (2018). Can urbanization process and carbon emission abatement be harmonious? New evidence from China. *Environmental Impact Assessment Review*, *71*, 70–83. https://doi.org/10.1016/j.eiar.2018.04.005

Yu, S., Agbemabiese, L., & Zhang, J. (2016). Estimating the carbon abatement potential of economic sectors in China. *Applied Energy*, *165*, 107–118. https://doi.org/10.1016/j.apenergy.2015.12.064

Yuan, M., Zhang, H., Long, Y., Shen, R., Wang, B., & Liang, Y. (2019). Economic, energy-saving and carbon-abatement potential forecast of multiproduct pipelines: A case study in China. *Journal of Cleaner Production*, *211*, 1209–1227. https://doi.org/10.1016/j.jclepro.2018.11.144

Yue, X., Deane, J. P., O'Gallachoir, B., & Rogan, F. (2020). Identifying decarbonisation opportunities using marginal abatement cost curves and energy system scenario ensembles. *Applied Energy*, *276*, 115456. https://doi.org/10.1016/j.apenergy.2020.115456

Zeng, X., Zhou, Z., Liu, Q., Xiao, H., & Liu, W. (2020). Environmental efficiency and abatement potential analysis with a two-stage DEA model incorporating the material balance principle. *Computers & Industrial Engineering*, *148*, 106647. https://doi.org/10.1016/j.cie.2020.106647

Zhang, C., Zhou, B., & Tian, X. (2022). Political connections and green innovation: The role of a corporate entrepreneurship strategy in state-owned enterprises. *Journal of Business Research*, *146*, 375–384. https://doi.org/10.1016/j.jbusres.2022.03.084

Zhang, K., Yao, Y. F., Liang, Q. M., & Saren, G. (2021). How should China prioritize the deregulation of electricity prices in the context of carbon pricing? A computable general equilibrium analysis. *Energy Economics*, *96*, 105187. https://doi.org/10.1016/j.eneco.2021.105187

Zhao, Y., Wang, C., Sun, Y., & Liu, X. (2018). Factors influencing companies' willingness to pay for carbon emissions: Emission trading schemes in China. *Energy Economics*, *75*, 357–367. https://doi.org/10.1016/j.eneco.2018.09.001

Zhou, B., Zhang, C., Wang, Q., & Zhou, D. (2020). Does emission trading lead to carbon leakage in China? Direction and channel identifications. *Renewable and Sustainable Energy Reviews*, *132*, 110090. https://doi.org/10.1016/j.rser.2020.110090

Zhou, P., Zhou, X., & Fan, L. W. (2014). On estimating shadow prices of undesirable outputs with efficiency models: A literature review. *Applied Energy*, *130*, 799–806. https://doi.org/10.1016/j.apenergy.2014.02.049

How to cite this article: An, Y., Shi, X., Wang, Q., Yu, J., Zhou, D., & Zhou, X. (2023). China's manufacturing firms' willingness to pay for carbon abatement: A cost perspective. *Business Strategy and the Environment*, *32*(8), 5477–5486. https://doi.org/10.1002/bse.3431

APPENDIX A: CHINESE INDUSTRY CLASSIFICATION CODE

Index	Sub-sectors
C13	Processing of food from agricultural products
C14	Manufacture of foods
C15	Manufacture of wine, beverages, and refined tea
C16	Manufacture of tobacco
C17	Manufacture of textile
C18	Manufacture of textile wearing apparel
C19	Manufacture of leather, fur, feather, and related products footwear
C20	Processing of timber, manufacture of wood, bamboo, rattan, palm, and straw products
C21	Manufacture of furniture
C22	Manufacture of paper and paper products
C23	Printing, reproduction of recording media
C24	Manufacture of articles for culture, art, education sport activities, and entertainment products
C25	Processing of petroleum, coking
C26	Manufacture of raw chemical materials and chemical products
C27	Manufacture of medicines
C28	Manufacture of chemical fibers
C29	Manufacture of rubber and plastics
C30	Manufacture of non-metallic mineral products
C31	Smelting and pressing of ferrous metals
C32	Smelting and pressing of non-ferrous metals
C33	Manufacture of metal products
C34	Manufacture of general purpose machinery
C35	Manufacture of special purpose machinery
C36	Manufacture of transport car making
C37	Manufacture of railroads, ships, aerospace, and other transportation equipment
C38	Manufacture of electrical machinery and equipment
C39	Manufacture of computers, communication equipment, and other electronic equipment
C40	Manufacture of measuring instruments
C41	Manufacture of others
C42	Comprehensive utilization of waste
C43	Repair of metal products, machinery, and equipment