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Economic policy uncertainty and corporate environmental performance: Evidence from COD in China

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Abstract: Few studies have examined the heterogeneous effects of regional EPU on corporate environmental performance (CEP) at the micro firm level. Using China's Environmental Statistics Database (CESD), we investigated the effect of provincial EPU on chemical oxygen demand (COD) emissions and found that higher EPU has promoted CEP by reducing COD emissions, which passed endogeneity tests and robustness tests. We also ascertained that three channels of EPU affect CEP: upgrading technology, loosening credit constraints, and reducing production. Our empirical results shed light on important implications for studying the micro-behavior of firms, especially environmental behavior, in developing economies.

Keywords: economic policy uncertainty; corporate environmental performance; chemical oxygen demand emission

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1. Introduction

In recent years, numerous scholars have focused on the influence of economic policy uncertainty (EPU) on macro- and microeconomics around the world. Research on EPU has experienced rapid growth since Baker, Bloom, and Davis (2016) had constructed the classic EPU index for most major countries. However, there are few studies on the relationship between EPU and corporate environmental performance (CEP) as not many countries are able to provide high-quality data on the environmental performance of firms at the micro level. In addition, most studies use a homogeneous EPU index at the country level, and there is a lack of a regional EPU index to detect the heterogeneous impact of EPU on CEP. With the publication and widespread usage of China's Environmental Statistics Database (CESD), an increasing number of researchers have focused on the relationship between EPU and enterprises' micro-level environmental performance. They have conducted meaningful studies on EPU from the perspectives of central supervision (Zhang, Chen, and Guo 2018), bank deregulation (Chen et al. 2021), environmental regulation (He, Wang, and Zhang 2020), and so on. However, the environmental deterioration caused by pollution can have both economic and social consequences. Thus, it is imperative to explore the effects of EPU on the environmental performance of enterprises.

Compared with the current research, our study makes three contributions to the literature. First, we add to the literature on the consequences of EPU. Existing literature mainly focuses on the impact of EPU on macroeconomic and financial variables and firms' investment decisions. While few studies pay attention to the impact of EPU on CEP at the firm level, our study is relatively early in its focus on this area. Second, previous EPU studies used the classic EPU index (Baker, Bloom and Davis 2016; Huang and Luk 2020), which is homogeneous and measures EPU across the country. However, following Yu et al.'s (2021) study, we adopt the provincial EPU of 31 provinces in China to investigate the heterogeneous effects of EPU on CEP in different regions. Third, we examine the mechanism by which EPU affects CEP, and find three channels: upgrading technology, losing credit constraints, and reducing production. Moreover, we provide strong evidence for solid empirical findings through a series of endogeneity and robustness tests. China is the largest developing economy in the world, and it is a study of enormous significance to investigate the environmental performance of Chinese firms under different EPU backgrounds. Our study of China's case has important policy implications to improve the environmental performance of developing countries and make the world move toward green and sustainable development.

The remainder of the paper is structured as follows: section 2 briefly reviews the literature and proposes some hypotheses. Section 3 introduces the data and the methodology used. Section 4 presents the empirical analysis. Section 5 concludes the paper and discusses policy implications.

2. Literature review and hypothesis

Our study is related to three strands of the literature. The first strand concerns the factors influencing CEP. There are many such investigations, mainly on the firm- and macro-level factors affecting CEP. The firm-level factors include, but are not limited to, corporate financial performance (Hang, Geyer-Klingeberg, and Rathgeber 2019; Li et al. 2017; Nguyen et al. 2021; Trumpp and Guenther 2015), corporate research and development (R&D) investment (Alam et al. 2019), corporate governance (Nguyen et al. 2021; Walls, Berrone, and Phan 2012), corporate social responsibility (Chuang and Huang 2018; Kraus, Rehman, and Phillips 2020; Shaukat, Qiu, and Trojanowski 2016), corporate culture (Roscoe et al. 2019), board characteristics (Cordeiro, Profumo, and Tutore 2020; Elmagrhi et al. 2019; Glass, Cook, and Ingersoll 2016; Shaukat, Qiu, and Trojanowski, 2016; Villiers, Naiker, and Staden 2011), human resource management (Paille et al. 2014; Roscoe et al. 2019), technology progress (Belhadi et al. 2020; Rehman et al. 2021; Singh et al. 2020), and environmental information disclosure (Li et al. 2017). Most of these studies are empirical analyses that find significant evidence of connections between firm-level factors and CEPs.

Studies investigating the factors that influence CEP at the macroeconomic level are also emerging. For example, Sharfman, Shaft, and Tihanyi (2004) suggest that global competitive and institutional pressures lead firms to develop a high-level CEP to make them more competitive. More comprehensively, Hartmann and Uhlenbruck (2015) demonstrate that national institutional antecedents, such as legal, market, and social institutions, have also significantly affected CEP. Their findings show that firms located in countries with higher numbers of signed and ratified international environmental treaties, greater market freedom, larger numbers of non-governmental organizations, and more press freedom have higher levels of CEP. Zhang, Chen, and Guo (2018) establish that central supervision through the National Specially Monitored Firms (NSMF) program in China has significantly improved CEP by reducing firms' COD emission intensity. Sun et al. (2019) show that China's green credit policy has significantly bolstered CEP by reducing water pollution. More recently, Fan et al. (2020) provide evidence that reduced trade uncertainty improves CEP by reducing the SO_2 emissions of firms with emission caps in Chinese regions. Chen et al. (2021) demonstrate that bank deregulation can improve CEP in China by measuring the lower COD emission intensity after bank branching deregulation.

The second strand of literature concerns the impact of EPU on firms. According to Jin et al. (2018), EPU is the uncertainty associated with shocks to government regulatory, monetary, and fiscal policies that affect the environment in which individuals and institutions operate. Many empirical studies have found that EPU affects i) macroeconomic indicators (gross domestic product [GDP] by Gu et al. 2021; foreign direct investment [FDI] by Chen, Nie, and Ge 2019; outward foreign direct investment [OFDI] by Hsieh, Boarelli, and Vu 2019; exchange rate by Abid 2020; interest rates by Shaikh 2020; inflation by Balcilar, Gupta, and Joost 2017), ii) consumer behavior (Chen, Fu, and Zhan 2021), iii) tourism (Wu et al. 2020), and iv) economic activity (Sahinoz and Cosar 2018).

At the firm level, the literature demonstrates that EPU can impact corporate operations, behavior, and decision making in many aspects. The empirical investigations of Chen, Lee, and Zeng (2019) show that higher EPU leads firms to decrease short-term, long-term, and total investments in the U.S. market. Therefore, U.S. firms also reduce FDI and OFDI when encountering high-level EPU (Julio and Yook, 2016). From the perspective of corporate cash holdings, Duong et al. (2020) find that corporations increase their cash holdings in response to higher EPU in the U.S., which is consistent with the conclusion of a positive relationship between EPU and cash holdings in China (Feng, Lo, and Chan 2019). Researchers have also demonstrated that EPU is negatively associated with firms' innovation output in both the developed market of the U.S (Xu 2020) and the emerging market of China (Lou et al. 2022). Regarding innovation input, based on panel data of 8,583 firms from 20 countries or regions during the period 2007-2016, Cheng, Zhao, and Wu (2021) suggest that there is an inverted U-shape relationship between EPU and R&D expenditure, and the relationship is more significant in developing countries, such as China, than in developed countries. However, Jiang and Liu's (2020) findings obtained with Bayesian analysis show a generally positive relationship between EPU and firms' R&D expenditure, using data from 1,163 Chinese listed companies from 2008 to 2016. As regards corporate tax avoidance (CTA), Nguyen and Nguyen (2020) demonstrate that EPU induces precautionary motives for CTA by exacerbating external financing frictions in the U.S. Later, Shen et al. (2021) investigate Chinese listed firms and reached a contradictory conclusion that EPU significantly and negatively influences CTA within heterogeneous groups of firms.

The third strand is related to the effect of EPU on CEP. EPU plays a profound role in the extensive phenomena of firms; thus, in all probability, it can also affect CEP. Fan et al. (2020) demonstrate that reduced trade uncertainty decreases Chinese firms with emission caps' SO_2 emission intensity and total SO_2 emissions. Moreover, by using data of 6,562 firms from 15 developed European countries from 2004 to 2017, Vural-Yavas (2021) illustrate that firms increase their overall CEP during periods of high uncertainty, where CEP is indicated by the average resource use, emissions, and environmental innovation scores. Most studies on EPU and CEP focus on the influence of EPU on carbon dioxide (CO_2) emissions, a specific indicator of CEP. Based on U.S. sector data, Jiang, Zhou, and Liu (2019) find a significant Granger causality from U.S. EPU to the growth of carbon emissions. In addition, Pirgaip and Dinçergök (2020) provide evidence of causality from EPU to CO_2 emissions in Canada, Germany, Italy and the U.S., and conclude that high-level EPU has a general effect on reducing CO_2 emissions. Furthermore, the findings of Adedoyin and Zakari (2020) imply that EPU is likely to have a positive effect on climate change for a short time by reducing CO_2 emissions in the U.K. However, Yu et al. (2021) aver that China's provincial EPU has a significantly positive impact on firms' carbon emission intensity.

These results suggest that examining the EPU is critical for COD emission intensity. Unfortunately, there have been few studies on whether and how EPU affects a firm's COD. To bridge this gap, we investigate the impact of EPU on the COD emission intensity of manufacturing firms in China. As expected, higher EPU affects energy consumption and economic growth, with implications for environmental sustainability and development. Based on the literature review, we propose the following hypothesis:

H1: Higher EPU can reduce the emission intensity of COD.

In addition to the causal relationship between EPU and CEP, we suggest that EPU affects COD mainly through three mechanisms: First, with a higher EPU, firms tend to survive in a turbulent environment by upgrading technologies such as enhancing pollutant discharge efficiency and increasing pollution abatement equipment (Gutiérrez and Teshima 2018; Fan et al. 2019; Fan et al. 2020; Levinson 2009). Second, loosening credit constraints can reduce pollutant emissions as well (Andersen 2016, 2017; Levine et al. 2019; Chen et al. 2021). Under loose credit conditions, firms can afford more liabilities to invest in pollution abatement facilities or upgrade technology. Third, in the face of the high uncertainty of the macroeconomy, companies might reduce production to deal with unexpected crises. Several studies have shown that EPU can affect pollutant emissions by reducing energy consumption (Adedoyin and Zakari 2020; Pirgaip and Dinçergök 2020). Based on this fact, we formulated the following hypotheses:

H2: Higher EPU can increase pollutant discharge efficiency and pollution abatement equipment.

H3: Higher EPU can reduce pollutant emissions by loosening credit constraints.

H4: Higher EPU can reduce pollutant emissions by cutting down production.

3. Data and methodology

3.1. Data

Measurement of provincial EPU

Based on the methodology of Baker, Bloom, and Davis (2016), Yu et al. (2021) constructed a set of EPU indices at the provincial level in China[1]. Their measurement of provincial EPU has significantly improved upon and is more advantageous than the Baker EPU index from three perspectives: First, the provincial EPU is more accurate, reliable, and comprehensive. The Baker EPU index was screened and constructed using English keywords, which usually have less complicated semantics than Chinese keywords. Second, the Yu EPU index is province specific, with broader coverage, and thus can capture regional heterogeneity. However, the Baker EPU index treats China as a homogenous entity and is skewed toward South China, having used only one English newspaper in Hong Kong. Third, the Yu EPU index has different denominations from the Baker EPU index and excludes non-economic news, as much of the news in the provinces is related to literature, sports, and culture rather than economics.

Measurement of CEP

There are several common proxies for measuring the CEP in China, such as carbon emissions (Adedoyin and Zakari 2020; Jiang, Zhou, and Liu 2019; Pirgaip and Dinçergök 2020; Yu et al. 2021), sulfur dioxide (SO_2) emissions (Fan et al. 2020; Jiang, Lin, and Lin 2014) and wastewater (Jiang, Lin, and Lin 2014). Recently, chemical oxygen demand (COD) emissions, as a major indicator of CEP, have been widely used by researchers in Chinese studies (Chen and Guo 2018; Chen et al. 2021a; He, Wang, and Zang 2020; Kahn, Li, and Zhao 2015; Sun et al. 2019; Wang, Wu, and Zhang 2018; Zhang et al. 2018). COD is a measure of water pollution in environmental chemistry that measures the oxygen required to oxidize soluble and particulate organic matter in the water. Compared to other water pollutants, such as ammonia nitrogen (NH3-N) or biological oxygen demand (BOD), COD is discharged by most enterprises, whereas NH3-H and BOD usually are not. Therefore, firm-level pollution information is presented by COD emissions in our study. The data are from proprietary China's Environmental Statistics Database (CESD), which is administered annually by the Ministry of Environmental Protection (MEP). All CESD data are self-reported by the firms and compiled by the MEP. Therefore, CESD is recognized as the most extensive nationwide micro-dataset in China's environmental economy, and its reliability is guaranteed by the rigorous data quality standards of MEP.

Control variables

[1] See Yu et al. (2021) about more details to construct the provincial EPU in China.

In studies of EPU affecting CEP, the pollution level of enterprises is mainly and significantly affected by a firm's age and production level (Chen et al. 2021; Fan et al. 2020). Thus, the firm's age, age^2, and output are included in our models as firm-level control variables. Moreover, to better identify the effects of EPU and reduce the endogeneity problem, we also introduce controls for province-level characteristics, such as provincial GDP. Furthermore, to alleviate the problem of missing variables, we introduce several fixed effects, such as provincial fixed effects, time fixed effects, industry fixed effects, and the interaction term of time fixed effects and industry fixed effects.

In addition to the above variables, other variables are used to perform robustness checks and mechanism analyses in our study. Appendix I shows the definitions and sources of all variables used in this study. Table 1 presents the descriptive statistics of the main variables, and the variables show characteristics similar to those of Chen et al. (2021) and Yu et al. (2021).

Table 1. Summary of descriptive statistics.

Variable	Obs.	Mean	S.D.	Min	Median	Max
LnCOD emissions	154692	8.81	2.39	-2.30	8.81	17.80
LnCOD emission intensity	154692	-2.57	2.48	-16.19	-2.58	12.65
COD remove ratio	154678	0.44	0.40	-0.86	0.50	1.00
lnEPU	154692	2.80	0.79	0.01	2.94	4.32
IV	150200	2.86	0.69	0.03	2.92	4.12
Age	154692	12.65	12.64	1.00	9.00	99.00
Age2	154692	319.73	741.48	1.00	81.00	9801.00
Lnoutput	154692	11.37	1.60	0.00	11.27	19.24
LnGDP	154692	9.56	0.80	5.67	9.62	10.88
LnWastewater_rem_efi	113001	6.25	2.07	-4.61	6.21	17.66
LnSO_2_removals_efi	6142	6.53	4.17	-3.91	6.91	18.56
LNFixed_assets	154158	10.05	1.85	0.00	10.00	18.98
LnLiquLiab	152125	10.33	1.86	0.00	10.29	18.64
LLRatio	146029	0.89	0.21	-9.05	1.00	11.33
Ln_interest_expense	112182	6.84	2.07	0.00	6.90	15.32
LnNH3_N_yields	154622	6.64	2.72	-2.30	6.70	17.88
LnNH3_N_emission	154692	6.05	2.57	-2.30	6.09	16.66
LnNH3_N_emission_intensity	154692	-5.32	2.64	-17.61	-5.28	11.66
NH3_N_removals_ratio	154624	0.26	0.61	-178.50	0.00	4.72

Note: the definitions of variables can be seen from Appendix I.

3.2. Methodology

Following the methodology of Yu et al. (2021), the empirical model is specified as follows:

$$y_{ijt} = \alpha + \beta EPU_{pt} + X_{ijt} + C_{pt} + fixedeffects + \varepsilon_{ijt} \quad (1)$$

where y_{ijt} indicates the COD emissions of firm i in industry j in year t. EPU_{pt} represents the EPU index of province p in year t. X_{ijt} represents firm-level controls and C_{pt} represents province-level controls. $fixedeffects$ are various fixed effects, including provincial fixed effects (γ_p), year fixed effects (η_t), industry fixed effects (θ_j), and industry-year fixed effects (λ_{jt}). Furthermore, we clustered the standard errors at the industry level to allow the random perturbation terms of different firms at the same industry level to correlate across industries.

4. Empirical results

In this section, we investigate the impact of EPU on Chinese manufacturing firms' COD emissions and test the potential mechanism of firms' COD emissions on EPU.

4.1. Baseline results

Table 2 shows the effects of provincial EPU on firms' COD emissions. It can be seen that the coefficients of EPU are consistently significant at the 1% significance level, whether with various fixed effects or not, even by the cluster of industry level. These empirical results provide strong evidence that higher EPU distinctly reduces the emission intensity of COD, which verifies **H1**. More specifically, by clustering at the industry level in Column (6), a 1% increase in EPU can reduce COD emissions by 0.035%.

Table 2. The effects of EPU on firms' COD emissions.

	(1) LnCOD emissions	(2) LnCOD emissions	(3) LnCOD emissions	(4) LnCOD emissions	(5) LnCOD emissions	(6) LnCOD emissions
LnEPU	-0.120***	-0.038***	-0.074***	-0.039***	-0.035***	-0.035***
	(-16.28)	(-4.47)	(-8.40)	(-4.89)	(-4.31)	(-3.50)
LnOutput	0.444***	0.479***	0.472***	0.547***	0.548***	0.548***
	(121.20)	(131.65)	(129.24)	(155.38)	(155.53)	(14.26)
Age	-0.004***	-0.003***	-0.004***	0.003***	0.002**	0.002
	(-3.45)	(-2.73)	(-2.98)	(2.97)	(2.12)	(0.90)
Age2	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(8.06)	(8.04)	(8.15)	(8.69)	(9.39)	(5.66)
lnGDP	-0.460***	-0.904***	0.667***	-0.002	-0.011	-0.011
	(-62.67)	(-64.96)	(5.27)	(-0.02)	(-0.09)	(-0.04)
Constant	8.494***	12.091***	-2.735**	2.586**	2.664**	2.664
	(105.73)	(89.66)	(-2.26)	(2.24)	(2.25)	(1.17)
Province FE	No	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	Yes	No	No
Industry FE	No	No	No	Yes	No	No
Industry*Year FE	No	No	No	No	Yes	Yes
Cluster	No	No	No	No	No	Yes
Obs.	154692	154692	154692	150873	150873	150873
Adj R2	0.103	0.167	0.171	0.318	0.323	0.323

t statistics in parentheses

[*] $p < 0.1$, [**] $p < 0.05$, [***] $p < 0.01$

4.2. Tackling the endogeneity problem

Following Yu et al. (2021), we use one lag of EPU (EPU_{-1}) as the instrumental variable (IV) to alleviate the endogeneity problem depicted in Table 3. It can be seen that the coefficient of IV in the first-stage regression of Column (1) is significantly positive at the 1% level, and the *p*-value of F is close to 0, which means that one lag of EPU is a good IV for EPU. Column (2) shows that the coefficient of EPU in the second-stage regression is significantly negative, which indicates that the empirical results in Table 3 are consistent with the results in Table 2, using IV regressions. Moreover, the increase in the absolute value of coefficients from 0.035 (Column (6) in Table 2) to 0.139 (Column (2) in Table 3) indicates that the abatement effect of EPU on COD emissions has improved to a great extent.

Table 3. IV regression for the effect of EPU on firms' COD emissions.

	(1)	(2)
	LnEPU	LnCOD emissions
IV ($LnEPU_{-1}$)	0.522***	
	(157.16)	
LnEPU		-0.139***
		(-6.03)
LnOutput	-0.007***	0.547***
	(-6.77)	(146.74)
Age	0.001**	0.002*
	(2.13)	(1.85)
Age2	-0.000**	0.000***
	(-2.53)	(9.39)
Province FE	Yes	Yes
Industry*Year FE	Yes	Yes
Cluster	Yes	Yes
First-stage Cragg and Donald test	(*p*-value < 0.001)	
F2 value		5940.9072
F2 Pvalue		0.0000
Obs.	146381	146381
Adj R2		0.1447

t statistics in parentheses
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Note: IV is lag value of ln Chinas provincial EPU index

4.3. Robustness checks

The basic models in Table 2 show the empirical results obtained by excluding outliers. However, the empirical results may be affected by the culling rules. Thus, we further use different winsorization standards to test the robustness of our models, as shown in Table 4. Columns (1)–(5) are winsorized at the 1%-99%, 2%-98%, 3%-97% level, 4%-96% level, and 5%-95% levels, respectively. All empirical results in Table 4 are nearly the same as the results in Column (6) of Table 2, which verifies the robustness of the baseline results.

Table 4. Robustness regressions for the effect of EPU on firms' COD emissions.

	(1) LnCOD_emission（1 99）	(2) LnCOD_emission（2 98）	(3) LnCOD_emission（3 97）	(4) LnCOD_emission（4 96）	(5) LnCOD_emission（5 95）
LnEPU	-0.035***	-0.034***	-0.034***	-0.034***	-0.034***
	(-3.44)	(-3.48)	(-3.52)	(-3.55)	(-3.54)
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No
Industry FE	No	No	No	No	No
Industry*Year FE	Yes	Yes	Yes	Yes	Yes
Cluster	Yes	Yes	Yes	Yes	Yes
Obs.	150873	150873	150873	150873	150873
Adj R^2	0.326	0.326	0.325	0.325	0.324

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.4. Mechanism analysis

Channel 1: Upgrading technology

Table 5 shows the first channel of EPU affecting CEP, which is that higher EPU can promote technology upgrades to increase pollutant discharge efficiency and pollution abatement equipment. Columns (1) and (2) indicate that an increase in EPU significantly improves the governance efficiencies of wastewater and SO_2, respectively. Moreover, there is no specific indicator denoting pollution treatment equipment in financial statements; thus, we directly use fixed assets as a proxy indicator for enterprise technology upgrade, since pollution treatment equipment usually belongs to fixed assets. Column (3) demonstrates that a higher EPU significantly increases enterprises' fixed assets. To this extent, a higher EPU encourages enterprises to upgrade technology, reduce COD emissions, and improve CEP.

Table 5. The channel of upgrading technology.

	(1) LnWastewater_remove efi	(2) $LnSO_2$ removals efi	(3) LnFixed assets
LnEPU	0.022*	0.222*	0.024***
	(1.92)	(1.69)	(2.76)
LnOutput	0.524***	0.569***	0.888***
	(12.73)	(10.07)	(35.68)
Age	0.005	0.017**	0.005*
	(1.18)	(2.08)	(1.76)
Age2	0.000***	-0.000	0.000*
	(2.79)	(-0.52)	(1.79)
LnGDP	-0.031	-2.148**	-0.297**
	(-0.10)	(-2.12)	(-2.16)
Constant	0.322	19.691*	2.629**

	(0.12)	(1.94)	(2.24)
Province FE	Yes	Yes	Yes
Industry*Year FE	Yes	Yes	Yes
Cluster	Yes	Yes	Yes
Obs.	110417	5273	151120
Adj R^2	0.338	0.757	0.639

t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Channel 2: Loosening credit constraints

Referring to the studies of Levin et al. (2019) and Chen et al. (2021), we evaluate the impact of corporate credit constraints on pollutant emissions and found that, with higher EPU and more relaxed credit conditions, firms change their corporate debt structure by increasing current liabilities and interest expenditures. Table 6 reveals that the current liabilities in Column (1), the ratio of current liabilities to liabilities in Column (2), and interest expenditure in Column (3), all significantly rise with an increase in EPU.

Table 6. The channel of loosening credit constraints.

	(1)	(2)	(3)
	LnLiquLiab	LLRatio	Lninterest expense
LnEPU	0.029^{***}	0.002^{**}	0.045^{***}
	(4.21)	(2.45)	(3.93)
LnOutput	0.859^{***}	-0.010^{***}	0.900^{***}
	(52.20)	(-3.89)	(34.97)
Age	0.017^{***}	0.000	0.015^{***}
	(7.48)	(0.78)	(5.28)
Age2	-0.000	-0.000^{***}	-0.000^{**}
	(-0.84)	(-3.83)	(-2.16)
LnGDP	-1.127^{***}	-0.073^{***}	-0.961^{***}
	(-8.36)	(-3.52)	(-3.91)
Constant	11.070^{***}	1.692^{***}	5.319^{**}
	(8.84)	(8.38)	(2.37)
Province FE	Yes	Yes	Yes
Industry*Year FE	Yes	Yes	Yes
Cluster	Yes	Yes	Yes
Obs.	149085	142970	109469
Adj R^2	0.617	0.068	0.481

t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Channel 3: Reducing production

Some scholars have already proven that enterprises will reduce production in response to an increase in EPU (Adedoyin and Zakari 2020; Pirgaip and Dinçergök 2020). Furthermore, lower production results in lower energy consumption and pollutant emissions. Thus, in Table 7, Column (1) shows that higher EPU leads to a significant reduction in production. In addition, owing to the reduction in production and energy consumption, the COD emission intensity significantly decreased in Column (2), and the COD removal ratio significantly increased in Column (3). These empirical results provide convincing evidence that a higher EPU reduces COD emissions.

Table 7. The channel of production reduction.

	(1) Lnoutput	(2) LnCOD emission intensity	(3) COD remove ratio
LnEPU	-0.045***	-0.035***	0.010***
	(-5.99)	(-3.50)	(3.11)
Age	0.013***	0.002	0.001
	(4.00)	(0.90)	(1.40)
Age2	-0.000	0.000***	-0.000*
	(-0.51)	(5.66)	(-2.02)
LnGDP	0.825***	-0.011	-0.074*
	(4.71)	(-0.04)	(-1.77)
LnOutput		-0.452***	0.040***
		(-11.79)	(8.55)
Constant	3.448**	2.664	0.664*
	(2.04)	(1.17)	(1.70)
Province FE	Yes	Yes	Yes
Industry*Year FE	Yes	Yes	Yes
Cluster	Yes	Yes	Yes
Obs.	151642	150873	150930
Adj R^2	0.192	0.368	0.210

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.5. Other pollutant emissions

Our previous study only investigated the effect of EPU on COD emissions, whereas Table 8 further demonstrates the effect of EPU on firms' pollutant (NH3-N) emissions. We find that a higher EPU reduces NH3-N and COD emissions. More specifically, the production of NH3-N, emission of NH3-N, and emission intensity of NH3-N significantly decreases with an increase in EPU, and the removal rate of NH3-N significantly surges under higher EPU.

Table 8. The effect of EPU on firms' other pollutant emissions.

	(1) LnNH3-N yields	(2) LnNH3-N emission	(3) LnNH3-N emission intensity	(4) NH3-N removals ratio
LnEPU	-0.029**	-0.046***	-0.046***	0.011**
	(-2.68)	(-3.78)	(-3.78)	(2.50)
LnOutput	0.597***	0.531***	-0.469***	0.025***
	(12.69)	(12.44)	(-10.98)	(8.09)
Age	0.005	0.004	0.004	0.000

	(0.97)	(0.95)	(0.95)	(0.69)
Age2	0.000**	0.000***	0.000***	-0.000**
	(2.08)	(3.39)	(3.39)	(-2.35)
LnGDP	-0.690**	-0.304	-0.304	-0.084
	(-2.24)	(-1.03)	(-1.03)	(-1.41)
Constant	6.412**	2.907	2.907	0.751
	(2.41)	(1.16)	(1.16)	(1.28)
Province FE	Yes	Yes	Yes	Yes
Industry*Year FE	Yes	Yes	Yes	Yes
Cluster	Yes	Yes	Yes	Yes
Obs.	151571	151642	151642	151573
Adj R^2	0.274	0.257	0.290	0.052

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5. Conclusions and implications

The effect of EPU on CEP has received increasing attention from all sectors of society in China. However, most studies use a homogeneous EPU index across China (Baker, Bloom, and Davis 2016; Huang and Luk 2020), which fail to examine the heterogeneous effects of EPU on CEP in different regions of China. China is a vast country with great differences in perspectives among regions, such as the level of economic development. Therefore, we followed the latest study, using provincial EPU (Yu et al. 2021), and investigated the role of provincial EPU in corporate pollution emissions. We found strong evidence that higher EPU significantly reduces COD emissions, which pass the IV and robustness tests. Furthermore, we explored three potential channels of EPU to reduce COD emissions and found that a higher EPU forces enterprises to upgrade technology and thus reduce COD emissions. Second, a higher EPU fosters the relaxation of credit constraints and improves liability structure. Thus, firms can invest more in pollution abatement to reduce their COD emissions. Third, to respond to a higher EPU, firms usually reduce production, as a result of which COD emissions also decrease. In addition, we found that EPU not only significantly reduced COD emissions but also other pollutant emissions, such as NH3-H.

These findings and the three-channel analysis have the following implications: First, enterprises usually adjust their pollution control strategy toward a better environmental performance in response to the aggravation of EPU, regardless of whether these adjustments are active or passive, which is a beneficial development for to society. Second, for corporate policymakers and managers, enterprises face more uncertainty risk when EPU increases, which has a negative effect on production, with concomitant lower output. However, it is a good opportunity to promote technological upgrading policies at a lower cost and with the difficulty of pollution control. Finally, due to data limitations, we only considered China's case; however, as the largest developing economy, a good CEP of Chinese enterprises under a high EPU provides valuable and practical experience for other economies. We, therefore, look forward to more studies based on pollution control data from micro-enterprises in other developing countries and to assess the environmental performance of enterprises in pollution control.

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Conflicts of interest

The authors declare no conflict of interest.

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Appendix

Appendix I: The definitions and sources of all variables

Variable	Definition	Source
Ln COD emissions	Emissions of chemical oxygen demand (COD, with log transformation), an important indicator of water pollution measured in kilograms.	China's Environmental Statistics Database (CESD)
Ln COD emission intensity	COD emissions per unit of output value (with log transformation), measured by log (COD emissions/output value).	CESD
COD remove ratio	The ratio of the removal amount to the yield amount of COD (*COD removals/COD yields*).	CESD
Ln EPU	Economics Policy Uncertainty where the firm is located (EPU, with log transformation).	Yu et al. (2021)
IV	One-period lag for Ln EPU.	Yu et al. (2021)
Age	Firm's age since its establishment.	Annual Surveys of Industrial Firms (ASIF)
Age2	The squared term of firm's age.	ASIF
Ln output	Output value at present price (with log transformation).	ASIF

Ln GDP	Prefecture-level province's annual GDP measured in 10,000 CHY.	China Province Statistical Yearbooks
Ln wastewater remove efi	Wastewater treatment facility measured in tons per day (with log transformation).	CESD
Ln SO_2 removals efi	SO_2 desulfurization facility capacity measured in kilogram per hour (with log transformation).	CESD
Ln fixed assets	Value of major tangible assets including plant, property, and equipment, measured in 1,000 CHY (with log transformation).	ASIF
Ln liquliab	Liquidity liabilities measured in 1,000 CHY (with log transformation).	ASIF
LL ratio	Liquidity liabilities/(liquidity liabilities + long liabilities).	ASIF
Ln interest expense	Interest expense measured in 1,000 CHY (with log transformation).	ASIF
Ln NH3-N emission	Emissions of ammonia nitrogen (NH3-N, with log transformation), an important indicator of pollution, measured in kilograms.	CESD
Ln NH3-N yields	Yields of NH3-N during production measured in kilograms (with log transformation), and it holds that yields = emissions + removals.	CESD
Ln NH3-N emission intensity	NH3-N emissions per unit of output value (with log transformation), measured by log (NH3-N emissions/output value).	CESD
NH3-N removals ratio	Removal of NH3-N during end-of-pipe abatement of pollutants per yields of NH3-N during production.	CESD

Tables

Table 1. Summary of descriptive statistics.

Variable	Obs.	Mean	S.D.	Min	Median	Max
LnCOD emissions	154692	8.81	2.39	-2.30	8.81	17.80
LnCOD emission intensity	154692	-2.57	2.48	-16.19	-2.58	12.65
COD remove ratio	154678	0.44	0.40	-0.86	0.50	1.00
lnEPU	154692	2.80	0.79	0.01	2.94	4.32
IV	150200	2.86	0.69	0.03	2.92	4.12
Age	154692	12.65	12.64	1.00	9.00	99.00
Age2	154692	319.73	741.48	1.00	81.00	9801.00
Lnoutput	154692	11.37	1.60	0.00	11.27	19.24
LnGDP	154692	9.56	0.80	5.67	9.62	10.88
LnWastewater_rem_efi	113001	6.25	2.07	-4.61	6.21	17.66
$LnSO_2$_removals_efi	6142	6.53	4.17	-3.91	6.91	18.56
LNFixed_assets	154158	10.05	1.85	0.00	10.00	18.98
LnLiquLiab	152125	10.33	1.86	0.00	10.29	18.64
LLRatio	146029	0.89	0.21	-9.05	1.00	11.33
Ln_interest_expense	112182	6.84	2.07	0.00	6.90	15.32
LnNH3_N_yields	154622	6.64	2.72	-2.30	6.70	17.88
LnNH3_N_emission	154692	6.05	2.57	-2.30	6.09	16.66
LnNH3_N_emission_intensity	154692	-5.32	2.64	-17.61	-5.28	11.66
NH3_N_removals_ratio	154624	0.26	0.61	-178.50	0.00	4.72

Note: the definitions of variables can be seen from Appendix I.

Table 2. The effects of EPU on firms' COD emissions.

	(1) LnCOD emissions	(2) LnCOD emissions	(3) LnCOD emissions	(4) LnCOD emissions	(5) LnCOD emissions	(6) LnCOD emissions
LnEPU	-0.120***	-0.038***	-0.074***	-0.039***	-0.035***	-0.035***
	(-16.28)	(-4.47)	(-8.40)	(-4.89)	(-4.31)	(-3.50)
LnOutput	0.444***	0.479***	0.472***	0.547***	0.548***	0.548***
	(121.20)	(131.65)	(129.24)	(155.38)	(155.53)	(14.26)
Age	-0.004***	-0.003***	-0.004***	0.003***	0.002**	0.002
	(-3.45)	(-2.73)	(-2.98)	(2.97)	(2.12)	(0.90)
Age2	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(8.06)	(8.04)	(8.15)	(8.69)	(9.39)	(5.66)
lnGDP	-0.460***	-0.904***	0.667***	-0.002	-0.011	-0.011
	(-62.67)	(-64.96)	(5.27)	(-0.02)	(-0.09)	(-0.04)
Constant	8.494***	12.091***	-2.735**	2.586**	2.664**	2.664
	(105.73)	(89.66)	(-2.26)	(2.24)	(2.25)	(1.17)
Province FE	No	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	Yes	No	No
Industry FE	No	No	No	Yes	No	No
Industry*Year FE	No	No	No	No	Yes	Yes
Cluster	No	No	No	No	No	Yes
Obs.	154692	154692	154692	150873	150873	150873
Adj R2	0.103	0.167	0.171	0.318	0.323	0.323

t statistics in parentheses

[*] $p < 0.1$, [**] $p < 0.05$, [***] $p < 0.01$

Table 3. IV regression for the effect of EPU on firms' COD emissions.

	(1) LnEPU	(2) LnCOD emissions
IV ($LnEPU_{-1}$)	0.522***	
	(157.16)	
LnEPU		-0.139***
		(-6.03)
LnOutput	-0.007***	0.547***
	(-6.77)	(146.74)
Age	0.001**	0.002*
	(2.13)	(1.85)
Age2	-0.000**	0.000***
	(-2.53)	(9.39)
Province FE	Yes	Yes
Industry*Year FE	Yes	Yes
Cluster	Yes	Yes
First-stage Cragg and Donald test	(*p*-value < 0.001)	
F2 value		5940.9072
F2 Pvalue		0.0000
Obs.	146381	146381
Adj R2		0.1447

t statistics in parentheses

* *p < 0.1*, ** *p < 0.05*, *** *p < 0.01*

Note: IV is lag value of ln Chinas provincial EPU index

Table 4. Robustness regressions for the effect of EPU on firms' COD emissions.

	(1) LnCOD_emission（1 99）	(2) LnCOD_emission（2 98）	(3) LnCOD_emission（3 97）	(4) LnCOD_emission（4 96）	(5) LnCOD_emission（5 95）
LnEPU	-0.035***	-0.034***	-0.034***	-0.034***	-0.034***
	(-3.44)	(-3.48)	(-3.52)	(-3.55)	(-3.54)
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No
Industry FE	No	No	No	No	No
Industry*Year FE	Yes	Yes	Yes	Yes	Yes
Cluster	Yes	Yes	Yes	Yes	Yes
Obs.	150873	150873	150873	150873	150873
Adj R^2	0.326	0.326	0.325	0.325	0.324

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5. The channel of upgrading technology.

	(1) LnWastewater_remove efi	(2) $LnSO_2$ removals efi	(3) LnFixed assets
LnEPU	0.022^{*}	0.222^{*}	0.024^{***}
	(1.92)	(1.69)	(2.76)
LnOutput	0.524^{***}	0.569^{***}	0.888^{***}
	(12.73)	(10.07)	(35.68)
Age	0.005	0.017^{**}	0.005^{*}
	(1.18)	(2.08)	(1.76)
Age2	0.000^{***}	-0.000	0.000^{*}
	(2.79)	(-0.52)	(1.79)
LnGDP	-0.031	-2.148^{**}	-0.297^{**}
	(-0.10)	(-2.12)	(-2.16)
Constant	0.322	19.691^{*}	2.629^{**}
	(0.12)	(1.94)	(2.24)
Province FE	Yes	Yes	Yes
Industry*Year FE	Yes	Yes	Yes
Cluster	Yes	Yes	Yes
Obs.	110417	5273	151120
Adj R^2	0.338	0.757	0.639

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6. The channel of loosening credit constraints.

	(1)	(2)	(3)
	LnLiquLiab	LLRatio	Lninterest expense
LnEPU	0.029***	0.002**	0.045***
	(4.21)	(2.45)	(3.93)
LnOutput	0.859***	-0.010***	0.900***
	(52.20)	(-3.89)	(34.97)
Age	0.017***	0.000	0.015***
	(7.48)	(0.78)	(5.28)
Age2	-0.000	-0.000***	-0.000**
	(-0.84)	(-3.83)	(-2.16)
LnGDP	-1.127***	-0.073***	-0.961***
	(-8.36)	(-3.52)	(-3.91)
Constant	11.070***	1.692***	5.319**
	(8.84)	(8.38)	(2.37)
Province FE	Yes	Yes	Yes
Industry*Year FE	Yes	Yes	Yes
Cluster	Yes	Yes	Yes
Obs.	149085	142970	109469
Adj R^2	0.617	0.068	0.481

t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7. The channel of production reduction.

	(1)	(2)	(3)
	Lnoutput	LnCOD emission intensity	COD remove ratio
LnEPU	-0.045***	-0.035***	0.010***
	(-5.99)	(-3.50)	(3.11)
Age	0.013***	0.002	0.001
	(4.00)	(0.90)	(1.40)
Age2	-0.000	0.000***	-0.000*
	(-0.51)	(5.66)	(-2.02)
LnGDP	0.825***	-0.011	-0.074*
	(4.71)	(-0.04)	(-1.77)
LnOutput		-0.452***	0.040***
		(-11.79)	(8.55)
Constant	3.448**	2.664	0.664*
	(2.04)	(1.17)	(1.70)
Province FE	Yes	Yes	Yes
Industry*Year FE	Yes	Yes	Yes
Cluster	Yes	Yes	Yes
Obs.	151642	150873	150930
Adj R^2	0.192	0.368	0.210

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8. The effect of EPU on firms' other pollutant emissions.

	(1) LnNH3-N yields	(2) LnNH3-N emission	(3) LnNH3-N emission intensity	(4) NH3-N removals ratio
LnEPU	-0.029**	-0.046***	-0.046***	0.011**
	(-2.68)	(-3.78)	(-3.78)	(2.50)
LnOutput	0.597***	0.531***	-0.469***	0.025***
	(12.69)	(12.44)	(-10.98)	(8.09)
Age	0.005	0.004	0.004	0.000
	(0.97)	(0.95)	(0.95)	(0.69)
Age2	0.000**	0.000***	0.000***	-0.000**
	(2.08)	(3.39)	(3.39)	(-2.35)
LnGDP	-0.690**	-0.304	-0.304	-0.084
	(-2.24)	(-1.03)	(-1.03)	(-1.41)
Constant	6.412**	2.907	2.907	0.751
	(2.41)	(1.16)	(1.16)	(1.28)
Province FE	Yes	Yes	Yes	Yes
Industry*Year FE	Yes	Yes	Yes	Yes
Cluster	Yes	Yes	Yes	Yes
Obs.	151571	151642	151642	151573

Adj R^2	0.274	0.257	0.290	0.052

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$