From Fines to Feathers: Enforcement Stringency, Protectionism, and Biodiversity

Panyu Li Yuchen Xu Luping Yu *

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Abstract

This study underscores the critical role of policy enforcement stringency in biodiversity conservation. Leveraging birdwatching records and the staggered institutional reforms that enhanced the independence of China's Environmental Protection Bureaus (EPBs) between 2003 and 2019, we find that greater EPB autonomy increased bird species richness by 25–36% and bird abundance by 24–35%. The reforms substantially increased the frequency of environmental penalties, which imposed both direct fines and indirect reputational and financial costs on firms. In response, firms reduced emissions and increased green innovation. Strengthened enforcement had disproportionately large effects on privately owned enterprises (POEs), while state-owned enterprises (SOEs) continued to avoid regulatory scrutiny due to persistent central protectionism. Overall, our findings highlight the substantial ecological costs of weak enforcement arising from incomplete administrative independence.

Keywords: Bird diversity, environmental enforcement, administrative independence, local protectionism, central protectionism
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*Panyu Li, Beedie School of Business, Simon Fraser University. E-mail: panyu_li@sfu.ca. Yuchen Xu, Business School, University of New South Wales. E-mail: yuchen.xu@unsw.edu.au. Luping Yu, Faculty of Business Administration, University of Macau. E-mail: lupingyu@um.edu.mo. We acknowledge the helpful comments from seminar participants at the University of New South Wales. All remaining errors and omissions are our own.

1 Introduction

The Earth does not belong solely to humans. However, several episodes of intense economic expansion have led to profound biodiversity loss, including large-scale species extinctions,[1] with serious and far-reaching consequences for humanity (Feir, Gillezeau, and Jones, 2024; Frank and Sudarshan, 2024).[2] In addition to pollution and climate risks, biodiversity loss introduces unique risks and challenges for economic and financial markets (Giglio, Kuchler, Stroebel, and Zeng, 2023; Hoepner, Klausmann, Leippold, and Rillaerts, 2023; Karolyi and Tobin-de la Puente, 2023). While recent research has begun to address these issues, it has primarily focused on investor recognition of firm exposure to biodiversity risks (Garel, Romec, Sautner, and Wagner, 2024), as well as the financial implications of biodiversity risks or conservation policies (e.g., Chen, Chen, Cong, Gao, and Ponticelli, 2024; Giglio, Kuchler, Stroebel, and Wang, 2024). Relatively little research has explored real variations in biodiversity or methods to reverse biodiversity loss.

Governments worldwide have implemented extensive environmental regulations and policies to combat environmental degradation, including biodiversity loss.[3] Beyond policy creation, the stringency of enforcement critically influences policy effectiveness.[4] For firms, the anticipated rigor of policy enforcement significantly influences how they per-

[1]For reference, in his *Sapiens: A Brief History of Humankind*, Harari (2014) discusses how human economic activities have significantly impacted species extinction throughout history. Dating back to the Cognitive Revolution (c. 70,000 BCE), humans' advanced hunting skills led to the extinction of large animals, such as the woolly mammoth, woolly rhinoceros, and giant deer in Europe, as well as megafauna in Australia and North America. Similarly, the Agricultural Revolution (c. 10,000 BCE) caused habitat changes and biodiversity loss due to farming practices. The Unification of Humankind (c. 1st century) intensified environmental degradation as human societies expanded. The Scientific Revolution (c. 16th century) and the Industrial Revolution (c. 19th century) further accelerated pollution and the over-exploitation of natural resources, leading to increased species extinction rates. Harari emphasizes that these patterns of extinction are direct consequences of humanity's relentless expansion and exploitation of ecosystems. The past decade has also seen a dramatic increase in the number of endangered species, with over 44,000 species at risk as of 2023 (Statista, 2024).

[2]Estimates suggest that degrading ecosystems could potentially trigger a decline of US$2.7 trillion in global GDP by 2030 (United Nations Development Programme, 2022).

[3]For example, governments worldwide have recently committed to addressing biodiversity loss together. At COP15 in 2022, a total of 188 governments agreed to the Kunming-Montreal Global Biodiversity Framework and committed to addressing the ongoing loss of terrestrial and marine biodiversity.

[4]For example, during the 2008 Olympics, Beijing implemented strict environmental enforcement on industrial production and construction activities. Reportedly, the air pollution index in Beijing dropped from an average of 102 before the Olympic Games to an average of 55 during the Olympics, representing a decline of approximately 50%. However, this improvement was temporary, and air quality returned to previous levels after the Olympic Games concluded (Chen, Jin, Kumar, and Shi, 2013).

ceive penalty risks and their resulting conservation efforts (Blundell, Gowrisankaran, and Langer, 2020). Policy enforcement stringency, therefore, has implications for both financial and environmental outcomes (Choy, Jiang, Liao, and Wang, 2024). This paper aims to examine the direct and indirect costs of enforcement stringency imposed on firms and quantify its ultimate impact on biodiversity. We also investigate the underlying mechanisms and their implications for different types of firms.

The Chinese context provides unique exogenous variation in the enforcement stringency of environmental regulations. Driven by the country's political tournament regime (Li and Zhou, 2005) and fiscal federalism (Qian and Roland, 1998), local officials in China have been heavily incentivized to prioritize economic growth targets over the past few decades (Lo, Fryxell, and Wong, 2006; Liu, Xu, Yu, Rong, and Zhang, 2020). This relentless focus on economic development has led to lenient enforcement of environmental regulations at the local level (Ma and Ortolano, 2000; Wang, Mamingi, Laplante, and Dasgupta, 2003), compromising environmental sustainability and resulting in excessive pollution and significant damage to ecosystems (Yu, Li, Duan, and Song, 2023).[5] In response, the Chinese central government introduced "vertical management reform" which increased the administrative independence of local Environmental Protection Bureaus (EPBs).[6]

Prior to the reform, local EPBs were under the control of local governments, creating inherent conflicts of interest in enforcing environmental laws since local governments prioritized economic development. In the early 2000s, cities began implementing the reform, which transferred local EPBs' enforcement authority to higher administrative levels, effectively removing local government control. Centralizing regulatory oversight and increasing local EPBs' administrative independence in this way has enabled more rigorous and impartial environmental law enforcement. We leverage the staggered city-level EPB reforms between 2003 and 2019 and employ a difference-in-differences (DiD) approach to evaluate whether the reforms have increased environmental law enforcement stringency and to investigate how more stringent enforcement may influence biodiversity outcomes.

[5] See "Beijing Says It Cares About Climate but Prioritizes Growth" (Ezrati, 2023).

[6] See Figure 3 for a schematic diagram illustrating the reform.

Because overall biodiversity is multidimensional and difficult to measure, we focus on avian diversity to capture variation in biodiversity. Scientifically defined, biodiversity encompasses the diversity of species, genetic variability within species, and variety among ecosystems and ecological processes. Although it is challenging to construct sensitive measures that capture variation in general biodiversity both over time and across regions, birds are among the best ecological indicators. They are highly sensitive to habitat changes and pollutants, making them effective proxies for assessing ecosystem health (U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, 2022). Furthermore, birds contribute to crucial ecosystem services, such as pollination, seed dispersal, and pest control, which makes their diversity essential for maintaining ecological balance.

To capture changes in bird diversity, we compile all available birdwatching records from both *eBird.com*, a global birdwatching platform, and *birdreport.cn*, a local Chinese birdwatching platform. We develop two avian diversity indicators: 1) bird species, which is the number of unique bird species observed within each city-year and serves as a proxy for species diversity, and 2) bird observation rate, which is the average number of birds observed per hour in each birdwatching event and serves as a proxy for bird abundance. To address concerns regarding the amateur nature of birdwatching activities and their potential limitations in observing all species, we cross-verify bird species' zoogeographical distribution with scientific monographs. These monographs determine bird distributions using more specialized and scientific methods, such as field photography, videography, audio recordings, satellite telemetry, and bird behavior recorders. Our analysis reveals that the *eBird.com* and *birdreport.cn* data accurately cover over 80% of species, with coverage increasing to 85–90% in most urban areas.

Using the staggered DiD strategy and controlling for various city-level and birdwatching-level covariates, our baseline findings show that more stringent environmental enforcement led to significant increases in bird diversity. The effect magnitudes are striking: cities saw an increase of 26.0 additional bird species (a 35.6% increase) and 25.8 more birds observed per hour (a 35.0% increase) following the Chinese EPB reforms.

To provide a concrete example, Figure 1 illustrates the expansion of Little Forktail (*Enicurus scouleri*) before and after EPB reforms. The figure depicts cities where Little Forktail was observed in 2014 (Panel B) and in 2018 (Panel C), alongside cities that underwent the EPB reform during 2015–2018. Little Forktail expanded its range significantly between 2014 and 2018, particularly into cities that implemented the reform during this period.

[Insert Figure 1 about here]

The baseline findings remain robust across a wide range of checks, including the use of standardized dependent variables, alternative filtering criteria, adjustments for observer ability, different sample periods, and additional control variables. Importantly, we find no systematic relationship between the timing of reform adoption and pre-reform biodiversity or environmental characteristics, alleviating concerns about endogenous policy timing. We also conduct heterogeneity analyses across bird species and show that the EPB reforms had particularly strong effects on endangered and migratory birds. The improvement in biodiversity is likely channeled through the overall enhancement of local environmental quality, consistent with the fact that reformed cities experienced substantial reductions in air, water, and solid waste pollution.

Our event-study analyses show that avian diversity increased immediately and sharply following the reform, raising the important question of where these new species originated. We distinguish between two possible mechanisms: a restoration effect, where improved enforcement restores the environment to its pre-degradation condition, and a redistribution effect, where reformed cities attract birds from neighboring areas. Our evidence indicates that the redistribution effect dominates in the short run. While these two mechanisms are not mutually exclusive, our results suggest that redistribution occurs rapidly, whereas genuine ecological restoration takes longer to materialize. These findings highlight the substantial ecological costs of weak enforcement.

In Section 4, we quantify the variation in enforcement stringency and examine the costs that enhanced scrutiny imposes on firms. Using Environmental Protection Administrative Penalties imposed on Chinese enterprises as a proxy for enforcement stringency, we document significant effects of the reforms: post-reform, the number of penalty cases increased by 152.3%, and total fines rose by 144.6%. To strengthen the causal interpretation between enforcement stringency and avian diversity, we divide cities into "stricter" (above median) and "looser" (below median) enforcement categories based on the magnitude of penalty increases surrounding EPB reform implementation. The results show that improvements in avian diversity are concentrated in the stricter cities.

Despite the significant increase in environmental penalties following the EPB reforms, the magnitude of fines remains modest, averaging RMB 58.7 thousand (approximately USD 8,260) per penalty event and about RMB 5 million (approximately USD 700,000) per city-year. This raises the question of whether and why firms respond to the increased likelihood of penalties.

We answer this question by investigating how environmental penalties affect firms' reputations and real economic outcomes. Focusing on the sample of listed firms that were penalized at least once during the sample period, we document substantial reputational and real costs of penalties. Specifically, following each penalty announcement, news sentiment toward the firm declines significantly during the five days after the event. The short-term cumulative abnormal returns (CARs) show significantly negative stock market reactions, with average returns of −0.15% to −0.20% in the [−1,3] and [−1,5] windows, respectively. Moreover, in years when a firm or its subsidiary was penalized, the listed parent firm faced higher debt costs, lower Tobin's Q, reduced institutional ownership, and slower sales growth. Taken together, although the monetary fines are relatively small, firms have strong incentives to avoid penalties due to the substantial reputational and financial repercussions.[7]

We then examine firms' conservation efforts in response to the "costly" penalties, as well as to the increased likelihood of being penalized. We find that firms reduce emissions not only after they themselves are penalized, but also after their peers (defined as firms in the same industry or located in the same city) are penalized. In other words, firms actively respond to not only penalties but also the perceived likelihood of penalties. Accordingly, the EPB reforms, which substantially increased the probability of penalties, led firms to lower their emissions. Further evidence shows that firms reduce emissions by increasing investment in green technologies rather than merely cutting production.[8] We use green

[7]These results are consistent with prior studies on how stakeholders respond to firms' negative ESG events. For example, brown suppliers experience reductions in contracts (Darendeli, Fiechter, Hitz, and Lehmann, 2022), and banks are more likely to terminate relationships with brown borrowers (Wang, 2023).

[8]As reported in Section Appendix A.3, city-level pollution declined whereas output remained stable post reform, indicating that firms likely did not lower emissions by curtailing production.

patent applications as a proxy for firms' investment in green initiatives and find that firms filed more green patents after being penalized, after their peers were penalized, and following the EPB reforms.

In Section 5, we examine whether the effects of the EPB reforms differ across firm types. Drawing from the literature on judicial and administrative independence (e.g., Liu, Lu, Peng, and Wang, 2022), we analyze the effects of the reform from the perspective of both local and central protectionism in China.[9]

Our findings show that post-reform enforcement has disproportionately regulated local and privately owned enterprises (POEs, including both listed and unlisted companies), while state-owned enterprises (SOEs) have not faced a significant increase in penalties. These results suggest that enhancing administrative independence has effectively curbed local protectionism, benefiting biodiversity by imposing stricter regulations on local firms, which now bear the increased costs of conservation efforts. However, central protectionism remains a significant challenge because SOEs are major contributors to pollution, and they continue to evade meaningful enforcement. This disproportionate effect indicates that while the reform has made progress in reducing local protectionism, further measures are necessary to address the privileged status of SOEs and mitigate their ongoing environmental impact.

Consistently, we also find that local and privately owned firms show a significant increase in green patent applications post-reform, reflecting their proactive efforts to hedge stricter environmental regulations. However, SOEs do not exhibit a comparable increase in green patents. This discrepancy points again to the persistent challenge of central protectionism: SOEs face fewer environmental regulations and are less motivated to invest in conservation efforts.

This research contributes to recent but emerging literature that integrates biodiversity into economic and finance frameworks. Beyond pollution, biodiversity loss has profound and far-reaching consequences for humanity (Feir et al., 2024; Frank and Sudarshan,

[9] Local protectionism arises when local governments shield firms that create local economic growth and tax revenue, often resulting in looser regulatory enforcement; central protectionism refers to state-owned enterprises (SOEs) receiving preferential treatment due to their connections with the central government. The increase in administrative independence of EPBs from local governments reduces regulatory leniency for local firms, while SOEs remain relatively insulated due to their political connections to the central government.

2024), introducing unique challenges for economic and financial markets (Giglio et al., 2023; Hoepner et al., 2023; Karolyi and Tobin-de la Puente, 2023; Cao, Karolyi, Xiong, and Xu, 2025). Accordingly, investors recognize biodiversity risks (Garel et al., 2024), and thus asset prices and financing costs react to biodiversity risks (Cherief, Sekine, and Stagnol, 2022; Hoepner et al., 2023; Coqueret, Giroux, and Zerbib, 2025; Cornaggia, Liang, Iliev, and Wang, 2025; Xin, Grant, Groom, and Zhang, 2025) and conservation policies (Chen et al., 2024). Studies also construct frameworks on how to leverage finance for conservation efforts (Flammer, Giroux, and Heal, 2025). Yet, understanding the extent to which economic activities have harmed biodiversity (Liang, Rudik, and Zou, 2025; Meng, Liu, Zhou, and Mei, 2025) is crucial for creating and enforcing conservation policies that can protect and improve biodiversity. Furthermore, examining which types of firms incur the economic costs of addressing biodiversity issues and which can evade them enhances our understanding of the conservation policy framework. By examining the dynamics of government actions, firm behavior, and biodiversity, this research underscores the importance of policy enforcement effectiveness—beyond investor preferences—in shaping firm conservation practices.

Second, we engage the extensive green finance literature.[10] Extant sustainable finance and ESG research largely focuses on the environmental considerations of firms and investors (e.g., Hartzmark and Sussman, 2019; Krueger, Sautner, and Starks, 2020; Bolton and Kacperczyk, 2021; Xu and Kim, 2022; Sautner, Van Lent, Vilkov, and Zhang, 2023; Starks, 2023; Edmans, Gosling, and Jenter, 2025), with far less attention given to the role of environmental regulation, particularly the effectiveness of enforcement. A significant motivation for firms to adopt green practices also stems from the implementation of environmental laws and policies (Greenstone, 2002; Blundell et al., 2020; Liu, Tan, and Zhang, 2021; Dasgupta, Huynh, and Xia, 2023; Ramadorai and Zeni, 2024), as these regulations introduce additional risks of penalties and litigation (Wu, Luo, and You, 2025) and consequent increased financing costs (Bartram, Hou, and Kim, 2022; Choy et al.,

[10] Despite the breadth of this literature, existing research on ESG can be broadly categorized in relation to several fundamental questions: who considers ESG (which investors and firms), why they consider it (their motivations), how they integrate ESG into decision-making, and what the outcomes of such integration are (particularly regarding financial implications). A central debate within this literature is the "value vs. values" question (Starks, 2023)—whether investors and firms should approach ESG and CSR as matters of social responsibility (e.g., Bénabou and Tirole, 2010) or from a financial perspective (e.g., Houston and Shan, 2022; Duchin, Gao, and Xu, 2025).

2024). However, enforcement of environmental regulations is inconsistent and likely influenced by factors such as firms' political connections (Heitz, Wang, and Wang, 2023). Inconsistent enforcement is particularly relevant for economically developing and geographically large countries such as China and India, where less stringent enforcement of environmental policies has consequences not only for pollution (He, Wang, and Zhang, 2020), but also for broader concerns, such as infant mortality (Greenstone and Hanna, 2014) and trade (Hering and Poncet, 2014). We contribute to the green finance literature by assessing the real impact of variations in environmental enforcement stringency on firm behavior and biodiversity.

Finally, our study addresses the implications of administrative and judicial independence in policy effectiveness. Imperfections in these policy enforcement systems can lead to local protectionism (Hay and Shleifer, 1998; Liu et al., 2022). As existing research has highlighted, judicial imperfections and local protectionism negatively impact economic growth (Fisman and Gatti, 2002; Bai, Du, Tao, and Tong, 2004; Gong, 2004; Ponticelli and Alencar, 2016; Barwick, Cao, and Li, 2021; Zhou, Liu, He, and Cheng, 2021; Li, 2022; Liu et al., 2022), including firm pollution (Stern, 2011; Kahn, Li, and Zhao, 2015; Zhang, Chen, and Guo, 2018; Axbard and Deng, 2024; Kong and Liu, 2024). In China, administrative and judicial systems are often influenced by political connections (Gong, 2004), contributing to both local (Bai et al., 2004) and central protectionism (Eaton and Kostka, 2017). In recent decades, the Chinese central government has implemented decentralization reforms across various departments to increase administrative and judicial independence (Xu, 2011; Wang, 2021; Cao, Liu, and Zhou, 2023). We study the efficacy of decentralization reforms in China and contribute empirical evidence to the literature that highlights the effectiveness of increasing the administrative independence of environmental bureaus as a strategy to reduce local protectionism and safeguard biodiversity.

Overall, our paper underscores the role of stringent environmental policy enforcement in mitigating the adverse impacts of corporate activities on ecosystems. Understanding the complex interactions between regulators, firms, and non-human species is crucial for developing policies that balance economic growth with environmental sustainability. Such policies ensure that economic objectives are pursued without compromising biodiversity or contributing to ecosystem degradation. Judicial and administrative independence, as we demonstrate, plays a vital role in ensuring the effective implementation of environmental regulations.

2 Data and sample

Our baseline analyses rely on panel datasets at the Chinese prefectural city level, spanning from 2003 to 2019. We start our sample in 2003 because the environmental penalty records required for the channel analysis, along with key annual city-level control variables, became systematically available from that year. We conclude our sample period in 2019 because the pandemic caused production suspensions and disruptions in government revenues that could affect both firm pollution and environmental regulation enforcement. The full sample comprises 277 cities from 31 provinces for which we also collected reform timing (which occurred between 1994 and 2024).

2.1 Avian diversity

We use avian diversity as a measure of biodiversity, given that birds are highly sensitive to habitat changes and pollutants, making them effective proxies for assessing ecosystem health. Avian diversity is also crucial for maintaining ecological balance, as birds provide essential ecosystem services, such as pollination, seed dispersal, and pest control.

To capture bird diversity, we utilize birdwatching records sourced from both *eBird.com* and *birdreport.cn*. *eBird.com* is a global platform managed by the Cornell Lab of Ornithology, allowing observers worldwide to submit bird sighting data across various times and locations. Similarly, *birdreport.cn* is a Chinese platform that enables local birdwatchers to log their observations.[11]

Both datasets report core variables for each birdwatching event (also called a checklist), including the names of the observed bird species, the count of birds observed, the location of the birdwatching activity, a unique birdwatching account ID, and the "effort

[11] *eBird.com*'s records trace back to the mid-19th century. Currently, millions of bird observations are logged monthly into its central database at the Cornell Lab of Ornithology. Scientists, land managers, and birdwatchers utilize this information to document changes in bird distributions, to identify bird populations requiring conservation, and to discover new species. Similarly, *birdreport.cn* is a Chinese platform that includes records dating back to the 1980s. For our sample period, we found a comparable volume of birdwatching records on both platforms.

hours", which we obtain by calculating the duration of the observation from the recorded start and end times. *eBird.com* further reports the distance traveled during the observation period in km, referred to as "effort distance", and the number of observers in each event. We compile all available birdwatching records and filter the data by excluding records that meet the following criteria: 1) event locations (latitude and longitude) that cannot be associated with a Chinese city, 2) effort hours less than 0.5 hours or more than 12 hours[12], and 3) records with missing or zero number of birds observed, or more than 50,000 birds observed. After filtering, we obtain approximately 46,800 unique birdwatching events from 2003 to 2019.

We construct two metrics to measure avian diversity: bird species and bird observation rate. Bird species richness is defined as the total number of unique bird species observed within a given city-year across all birdwatching events. This metric captures the diversity of bird species present in the area. Bird observation rate, which we construct at the event level, serves as a measure of bird abundance and is defined as the number of birds observed per hour. To address the presence of outliers, we winsorize each metric by city at the 2.5% level.

[Insert Table 1 about here]

Table 1 presents the summary statistics. Among the 1,586 city-year observations with birdwatching records, an average of 73.0 unique bird species are observed per city-year. For each birdwatching event, an average of 73.8 birds is observed per hour. Figure B1 illustrates the spatial distribution of the 1,750 unique bird species observed from 2003 to 2019, showing that bird species are not highly concentrated in specific regions. Both the southwest and eastern coastal regions exhibit high species diversity.

To address concerns about the amateur nature of birdwatching and its potential limitations in capturing all species, we cross-verify bird species' zoogeographical distributions using scientific monographs. Specifically, we reference the three editions of *A Checklist*

[12]There is a trade-off between filtering the data and preserving all raw submissions. Because the dataset is based on amateur contributions, outliers are frequent and sometimes extreme. Appendix Table B1 reports summary statistics of the bird observation rate (birds observed per hour) conditional on the duration of each event. As shown, both the mean and the standard deviation are extremely high for events shorter than 0.5 hours, which justifies excluding those observations. Consistent with this view, both the mean and the standard deviation of the observation rate shrink substantially after 12 hours. In Appendix A.1, we further present robustness checks using alternative filtering criteria.

on the Classification and Distribution of the Birds of China (Zheng, 2005, 2011, 2017), which document all bird species in China and their occurrences across the country's 18 zoogeographical regions. These monographs rely on specialized and scientific observation and categorization methods, including field photography, videography, audio recordings, satellite telemetry, and bird behavior recorders. Zhang, Han, Xia, and Møller (2022) provide a description of these monographs and open-access datasets of the bird species lists.

We assess the coverage rate by comparing two datasets for each zoogeographical region: the complete list of bird species from Zheng's monographs (Zheng, 2005, 2011, 2017) and the list of bird species observed by amateurs on *eBird.com* and *birdreport.cn*. We then calculate the percentage of species in Zheng's list that were also reported on *eBird.com* and *birdreport.cn*. As shown in Figure 2, our analysis reveals that birdwatching data accurately covered 80.7% of species, with coverage increasing to 85–90% in most urban areas.[13]

[Insert Figure 2 about here]

2.2 Environmental Protection Bureau (EPB) reform

In China, the Environmental Protection Bureaus (EPBs) are responsible for monitoring environmental quality, enforcing regulatory compliance, and implementing policies to prevent and control pollution. These bureaus operate at national, provincial, city, and county levels. Prior to reforms, each level of government had control over its corresponding EPB: county governments managed county-level EPBs, while city governments oversaw city-level EPBs.

In 1994, China initiated a trial of "vertical management reform" for EPBs, aiming to enhance the effectiveness of environmental monitoring and enforcement by reducing the influence of local governments, which often prioritize local economic growth.[14] This

[13]Birdwatching records inevitably undercount the true number of species, as some birds might be too scarce or elusive to be detected by amateur observers. However, this limitation does not affect our interpretation, since our analysis relies on the time variation of observed species. A species becoming unobservable in certain years still reflects a decline in abundance and signals environmental stress.

[14]The objective of the EPB reform was explicitly outlined by the Ministry of Ecology and Environment of the People's Republic of China: *"For a long time, China has implemented a territorial-based environmental management system, which has led to many insurmountable problems. For instance, some*

reform increased the administrative independence of local EPBs by shifting control from county governments to higher city-level EPBs, enabling the city EPB to assume responsibility for the funding, staffing, and overall management of county-level EPBs.

[Insert Figure 3 about here]

Figure 3 presents a schematic diagram of this reform. Prior to the reform, the EPB control structure had been "horizontal"; following the reform, the EPB system transitioned to an independent "vertical" structure. Although this reform did not alter the physical structure of EPBs, it significantly changed their control mechanisms, which influenced incentives within the local administrative system. This change enhanced the administrative independence of the EPBs and was therefore expected to improve the effectiveness of regulatory enforcement.

We manually collect and verify the timing of the implementation of the reform for each city from official government website announcements and through direct calls to government offices. Our final sample includes timing data for 277 prefecture-level cities that implemented reforms between 1994 and 2024. To avoid measurement biases, cities for which we were unable to determine reform timing are omitted from our sample. During our sample period (2003–2019), a total of 233 cities underwent the reform. The 44 cities that implemented reform between 2020 and 2024 remain untreated in our sample period. The geographic distribution of reformed cities is presented in Appendix Figure B1.

2.3 Control variables

First, we collect city-year level socioeconomic covariates that might affect biodiversity and firm activities from City Statistical Yearbooks. Basic controls in our analysis include population density (population scaled by land area), urbanization rate (the proportion of

local governments prioritize development over environmental protection, focusing on economic growth while neglecting environmental concerns... ⋯Environmental responsibilities are not properly enforced, and the responsibilities of local governments often fall on local environmental protection departments. The existence of these issues seriously undermines the uniformity, authority, and effectiveness of environmental regulation, hindering the modernization of the national environmental governance system and its capabilities⋯⋯According to the original intent of the institutional design, the vertical management reform of environmental protection aims to strengthen the implementation of environmental protection responsibilities by local governments and their relevant departments. It seeks to resolve the interference of local protectionism in environmental monitoring, supervision, and law enforcement ..." (Ministry of Ecology and Environment of the People's Republic of China, 2016) a city's population residing in urban areas), the logarithm of GDP, industrial structure (the fraction of primary and secondary industry output over GDP), real estate investment to GDP ratio (China's most significant industry over recent decades), and green space ratio (the percentage of green land over total land area).

To account for climate variables that may influence bird diversity, birdwatching activity, and pollution levels, we incorporate average temperature (°C), precipitation (mm), wind speed (m/s), and the number of natural disasters into our analysis. Temperature, precipitation, and wind speed are calculated by averaging monthly latitude-longitude grid data sourced from the ERA5-Land dataset, a high-resolution global reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) (Muñoz Sabater, 2019). The number of disasters is sourced from The International Disaster Database (EM-DAT).

Finally, we consider birdwatching efforts and observer abilities that may influence birdwatching outcomes. For the city-year level analyses, we control for the total number of birdwatching events and the total hours spent observing (effort hours). At the birdwatching event level analyses, we control for effort hours and unique birdwatching account ID fixed effects. The latter captures observer ability. These data are directly obtained from *eBird.com* and *birdreport.cn*.

Detailed variable definitions for all above-mentioned variables are presented in Appendix Table B2.

2.4 Environmental penalties

EPBs play a critical role in overseeing firm-level emissions, assessing environmental impact, and promoting sustainable practices to protect ecosystems and public health. A key component of their enforcement is the issuance of environmental penalties, i.e., administrative sanctions imposed on firms that violate environmental protection laws. These penalties establish environmental administrative responsibilities and can include fines, production stoppages, and other specific measures. Penalties are typically issued for violations across four main pollution categories: air, water, solid waste, and industrial noise. Through these efforts, EPBs aim to curb pollution and encourage responsible corporate behavior.

We obtain data on the universe of environmental penalties imposed on Chinese enterprises since 2003 from China Enterprise Environmental Protection Administrative Penalty Data[15]. The dataset reports key variables for each penalty, including the company name, penalty date, penalty content (fine amount, orders, etc.), reasons for punishment, and the issuing EPB. Based on this information, we construct two variables: the number of penalties and the total amount of fines in million yuan (RMB) for each city-year. As shown in Table 1, each city-year has an average of 84.10 penalties, with a total fine amount exceeding RMB 4.93 million (approximately USD 700,000). When comparing the pre-reform and post-reform periods, on average, the number of penalties increased from 56.70 to 288.82 per city-year, and the total fine amount rose from RMB 3.16 million to 18.16 million per city-year. These numbers indicate that EPB reform has substantially impacted environmental enforcement.

To further refine our analysis of heterogeneous effects, we collect additional firm-specific information for all firms penalized during our sample period from *tianyancha.com*, a leading platform that aggregates comprehensive information on enterprises in China. Focusing on firm registration locations and ownership structures, we categorize firms into "local" or "non-local" based on whether their registration location matches that of the EPB that imposed the sanction. We define a firm as a state-owned enterprise (SOE) if *tianyancha.com* labels it as state-owned and as a privately owned enterprise (POE) if not.[16]

2.5 News sentiment

We utilize the news sentiment around penalty events to assess the potential reputational costs faced by penalized firms. The news data come from Datayes, a leading financial information provider in China that aggregates articles from both traditional and social media outlets. For each article, Datayes applies a BERT–CRF model combined with

[15] The dataset is provided by Qiyeyujingtong, or qyyjt.com.

[16] SOEs in China are defined as having either full or majority ownership by state institutions or significant control through ownership stakes held by local, regional, or central government entities. Chinese business data platforms, such as *tianyancha.com* and *qichacha.com*, track these ownership structures and classify companies accordingly to help users distinguish between state-owned, privately owned, and foreign-invested entities.

an attention-based CNN to identify the firms mentioned[17] and to generate a sentiment score toward each firm. The sentiment score ranges from −1 (most negative) to +1 (most positive). For each firm–day, we calculate the average sentiment score across all news articles focusing on that firm. The average sentiment is slightly positive (mean = 0.19 or 0.21), which aligns with the general tendency of news sentiment in China to be positive on average (Liu, Tan, Xu, Yuan, and Zhu, 2025).

Our empirical analysis focuses on listed firms that received at least one environmental penalty (indicating active engagement in polluting production) during the sample period (2003–2019). In total, we identify 2,320 penalties directly imposed on parent listed companies, covering 618 unique firms. When subsidiaries are included, the dataset expands to 8,937 penalties involving 1,551 firms. The regression analysis focuses on a symmetric event window of [-5, 5] days around each penalty announcement. Events are stacked, treating the penalized firm as the treated unit in its event window, while all other firms serve as controls.

2.6 Real costs

Penalties impose tangible economic costs on firms. Beyond the monetary fines (which are often relatively small), penalized firms might experience adverse financial consequences. We construct five measures to capture these costs and firm performance: (1) CAR ([-1, 3] and [-1, 5]), i.e. the cumulative abnormal return over the [-1, 3] or [-1, 5] day event window surrounding the penalty announcement. This measure captures the stock market's immediate valuation response to the penalty event. (2) Debt cost, defined as the ratio of net financial expenses to total debt (sum of non-current liabilities, short-term borrowings, and current portion of non-current liabilities).[18] This measure captures the firm's overall financing burden, reflecting how penalties influence creditors' perceptions and the firm's effective borrowing conditions. (3) Tobin's Q, calculated as the ratio of the market value of total assets to their book value. This measure captures the firm's

[17] Datayes assigns a relatedness score to each article–firm pair, indicating whether the firm is the primary focus or merely mentioned alongside others. In this study, we retain article–firm pairs in which the firm is the primary focus. The dataset covers only publicly listed firms in China.

[18] Net financial expenses include interest expenses (net of interest income), exchange losses (net of exchange gains), and related fees incurred for financing business operations. The value can be either positive or negative, depending on the relative magnitude of interest and exchange gains versus expenses.

growth opportunities and overall market valuation. (4) Institutional ownership, which is the proportion of tradable A-shares held by institutional investors in each firm-year. This measure reflects institutional investors' confidence and monitoring intensity following environmental violations. (5) Sales growth, i.e. the annual percentage change in a firm's sales revenue relative to the previous year. This measure captures the firm's real operating performance and potential product-market consequences of reputational damage.

Together, these five measures offer a comprehensive assessment of the financial performance and firm value implications of environmental penalties. The data are obtained from CSMAR and CNRDS, which are commonly used databases for stock prices and financial information of Chinese listed firms.

2.7 Firms' emissions

We construct a firm-year panel of emission data for all publicly listed firms in our sample from 2007 to 2019. The data are collected from two primary sources: (1) corporate environmental information disclosure reports and (2) government environmental information disclosure platforms. For each firm-year, we record annual emission indicators, including chemical oxygen demand (COD), ammonia nitrogen (NH_3–N), total nitrogen, total phosphorus, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and soot emissions. Together, these measures provide a multidimensional characterization of firms' air and water pollutant discharges.

In the regression analysis, each emission indicator is standardized to obtain its z-score, and the average of these z-scores is used as a composite index of firm-level pollution intensity, denoted *Standardized emissions*.

2.8 Green initiatives

We use the number of green patent applications to measure firms' engagement in green innovation. Patent records are obtained from the Chinese National Intellectual Property Administration (CNIPA), as provided by CNRDS. Patents are labeled as "green" according to the International Patent Classification (IPC) Green Inventory. The data cover both listed and unlisted firms and include detailed timestamps for both patent applications and approval.

We focus on applications rather than granted patents to better capture firms' proactive environmental initiatives while excluding the influence of administrative approval processes and firms' ability to secure patent grants. Moreover, since patent approval typically involves a substantial time lag, application data more accurately reflect the timing of firms' innovation efforts in response to environmental regulation and enforcement.

3 EPB Reform and Bird Diversity

3.1 Baseline results

Our baseline analyses examine the impact of Environmental Protection Bureau (EPB) reforms on bird species diversity in China. The reforms were implemented in a staggered manner across Chinese cities, which creates a natural setting for a Difference-in-Differences (DiD) analysis. The baseline Two-Way Fixed Effects (TWFE) regression model is specified as follows:

$$\textit{Bird species}_{i,t} = \alpha + \beta \times \textit{PostReform}_{i,t} + \gamma \times \mathbf{X}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}. \tag{1}$$

where the dependent variable, $\textit{Bird species}_{i,t}$, represents the total number of unique bird species observed in city i in a year t. The independent variable of primary interest, $\textit{PostReform}_{i,t}$, is a dummy variable that equals one if city i has experienced EPB vertical management reform on or after year t. The coefficient β of the $\textit{PostReform}_{i,t}$ captures the DiD effects of EPB reforms on bird diversity. $\mathbf{X}_{i,t}$ is a vector of city-year controls, including city population density, urbanization rate, city GDP (log), industrial structure, real estate investment to GDP ratio, green space ratio, temperature, precipitation, wind speed, and number of natural disasters. In addition, we control for covariates of birdwatching activities, including the number of birdwatching events and the total effort hours spent. The city fixed effects (μ_i) and the year fixed effects (λ_t) are included to absorb all time-invariant city effects on bird diversity and all annual shocks common to all cities, respectively. Standard errors are clustered at the city level.

We also perform a similar DiD regression at the event level. The dependent variable, *Bird observation rate*, measures bird abundance and is defined as the average number of birds observed per hour in each birdwatching event. In this model, we include both city-level controls and event-level controls to account for relevant covariates. The event-level analysis, in particular, allows us to further include the unique birdwatching account ID (observer ID) to control for observer ability.

Upon the implementation of the reform, the local EPBs are expected to enforce regulations more stringently. This stricter enforcement is expected to reduce pollution and consequently improve biodiversity. Consistent with our hypothesis, the empirical results in Table 2 indicate that cities experience a significant increase in bird diversity after reform.

[Insert Table 2 about here]

Specifically, columns 1–3 show that post-reform cities had an average increase of 18.35–25.98 additional bird species, representing a 25.1%–35.6% increase when evaluated at the sample mean (73.03). Columns 4–7 suggest that, on average, 17.53–25.80 more birds were observed in each birdwatching event in post-reform cities, representing a 23.8%–35.0% increase relative to the sample mean (73.78). The results are stronger after control variables are included. Column 7, which includes the birdwatching account ID to control for observer ability, reveals that even for the same observer, 25.80 more birds were observed per hour post-reform. These findings provide robust evidence that EPB reform has had a positive and significant impact on avian biodiversity in the treated cities.[19]

To assess the parallel trends assumption, we employ a dynamic DiD method. Figure 4 presents the parallel trends analysis by plotting event-study coefficients estimated using three approaches: a two-way fixed effects (TWFE) model, the stacked DiD approach (Cengiz, Dube, Lindner, and Zipperer, 2019)[20], and the method proposed by Sun and

[19]To account for potential spatial correlation among residuals, we adjust standard errors using the method proposed by Colella, Lalive, Sakalli, and Thoenig (2019). We define spatial correlation within a 219-kilometer radius, approximately three times the average city radius of 73 kilometers (calculated by assuming each city is a circle and using its land area). To enhance interpretability, Appendix Table B3 reports results using standardized dependent variables. The estimates indicate that, following the reform, bird species richness increased by 0.24 standard deviations, while the bird observation rate rose by 0.12 standard deviations.

[20]Traditional TWFE models can yield biased dynamic estimates in staggered DiD settings when

Abraham (2021)[21]. The results indicate that both bird species diversity and abundance increase significantly immediately after the reforms, suggesting a positive and contemporaneous effect of EPB reforms on avian biodiversity.

[Insert Figure 4 about here]

In Appendix A.1, we conduct a series of robustness checks, including (1) revisiting the filtering criterion (relaxing and tightening the effort hour thresholds), (2) accounting for observer ability, (3) using alternative sample periods, and (4) addressing potential confounding effects from environmental courts. Appendix A.2 further discusses the potential endogeneity of reform timing. Based on the results from a survival (hazard) model, we find no systematic relationship between the timing of reform adoption and pre-reform biodiversity or environmental characteristics.

3.2 Species heterogeneity: endangered and migrant birds

We perform heterogeneity tests based on bird species characteristics to gain deeper insights into the effects of EPB reforms on biodiversity.

First, we compare reform effects on endangered vs. non-endangered species to examine whether stronger enforcement has particular importance for threatened birds. Endangered species are identified following the National Key Protected Wildlife List (National Forestry and Grassland Administration, 2021), which flags species at risk. We classify bird species accordingly and construct the dependent variables for subsamples, i.e. the number of endangered and non-endangered bird species at the city-year level, and the bird observation rate for endangered and non-endangered species in each birdwatching event. As shown in Panel A of Table 3, the average number of endangered bird species (8.87) is only 13.3% of non-endangered species (66.87). Evaluated at the mean, EPB reforms increased the number of endangered species by 35.1%, compared to 24.3% for

treatment effects are heterogeneous (e.g., Baker, Larcker, and Wang, 2022). The stacked DiD approach restructures staggered treatment settings into a series of two-group, two-period comparisons. By "stacking" these event windows, the method mitigates the negative weighting problem and produces cleaner estimates of dynamic treatment effects.

[21] Sun and Abraham (2021)'s method employs a weighted estimator that interacts treatment timing with time fixed effects, enabling the calculation of average treatment effects for each period post-treatment. This approach reduces bias by avoiding the use of already-treated units as controls.

non-endangered species. This finding underscores the importance of enforcement stringency for protecting endangered species.

[Insert Table 3 about here]

Second, we compare reform effects on migratory vs. resident birds. Migrant species are expected to be more sensitive to environmental quality, as they can more readily adjust their migratory routes to avoid polluted areas (we will discuss these redistribution effects in the next section 3.3). We classify species using the *List of Migratory Birds in China* (Appendix Table A1 in National Forestry and Grassland Administration (2022)). As shown in Panel B of Table 3, EPB reforms had slightly larger effects on the number of migrant species (25.6%) than on resident species (21.4%) when evaluated at the mean. Notably, the reforms had minimal effects on the observation rates of resident birds.

3.3 Restoration or redistribution

The previous sections document that the EPB reforms are associated with significant increases in bird species richness, affecting various species groups. In particular, the event-study figures reveal that the impact of EPB reforms on bird diversity is both immediate and sharp. This raises an important question: where do these new species come from? In this section, we explore two potential mechanisms—restoration and redistribution.

Restoration refers to the recovery of previously degraded ecosystems. Since the 1990s, Chinese local governments prioritized economic growth at the expense of ecological integrity, leading to biodiversity loss.[22] If the reforms restore ecosystems toward their pre-expansion conditions, the estimated positive effects of EPB reforms on biodiversity can be interpreted as (a lower bound estimate of) the hidden biodiversity costs of decades of growth-first policies.

An ideal test of restoration would require comprehensive species lists from before the 1990s till now, allowing us to track whether species disappeared during economic expan-

[22] While China launched its reform and opening-up in 1978, its rapid economic growth gained momentum after 1992, following President Deng Xiaoping's push for deeper market-oriented reforms. Many studies identify the early 1990s as the starting point of China's economic miracle (e.g., Song, Storesletten, and Zilibotti, 2011).

sion but reappeared after the reforms. Lacking such long-term historical birdwatching data, we implement an imperfect but logically consistent test.

For each city undergoing reform, we construct (1) Post-reform species [0, 2]: species observed in the three years starting from the reform year;[23] (2) Pre-reform species [-3, -1]: species observed in the three years before reform; and (3) Historical species [≤-4]: species observed four or more years before reform.

From these lists, we define *new species* as those absent in the three years before reform ([-3, -1]) but observed in the first three years starting from the reform year ([0, 2]). On average, cities recorded 41.3 new species post-reform, representing 39.77% of all post-reform species. Among these, we further identify *reappeared species* as new species that had been observed historically, i.e. four or more years prior to reform [≤-4].[24] The average restoration ratio is 15.12% (Panel A, Figure 5), indicating that only a small share of newly observed species reflects long-term restoration.[25] While stricter enforcement might eventually contribute to ecological restoration, such effects materialize only in the long run, and previously disappeared species are unlikely to reemerge rapidly or in large numbers immediately after the reform.

[Insert Figure 5 about here]

A second potential channel is redistribution. If reforms improve local environmental quality relative to neighboring areas, species may relocate into the reformed city. To test this, we compile (4) Pre-reform neighbor species [≤-1]: species observed in adjacent cities before the focal reform year. We define *redistributed species* as those new to the focal city but previously observed in neighboring cities. The average redistribution ratio is 76.70% (Panel B, Figure 5), suggesting that most new species are attracted from nearby locations. Taken together, our results suggest that redistribution occurs rapidly, whereas genuine ecological restoration takes longer to materialize. These findings highlight the substantial ecological costs of weak enforcement.

[23] We focus on a 3-year window as most reforms occurred after 2014, particularly in 2016–2017.

[24] Put differently, these are species that were present in [≤-4], absent in [-3, -1], and then reappeared in [0, 2].

[25] This exercise provides a lower-bound estimate. Birdwatching records from four or more years before reform cannot fully capture the historical biodiversity prior to economic expansion.

In extended analyses, we evaluate the extent to which EPB reforms improved local environmental quality by examining their effects on air, water, and solid pollution indicators. Detailed discussions and results are reported in Appendix A.3. We also explore further the redistribution effects by examining spillover effects from neighboring cities' reforms on both biodiversity and pollution outcomes. Detailed discussions and results are reported in Appendix A.4.

4 Environmental Penalties and Impacts on Firms

This section investigates how the EPB reforms promoted biodiversity by strengthening enforcement and altering firms' environmental behavior.

4.1 Environmental penalties

To assess whether EPB reforms indeed enhanced environmental enforcement stringency, we use the environmental penalties imposed by EPBs on corporations as a proxy for enforcement strength. Although penalties alone can be an ambiguous indicator—low penalty counts might signify either weak enforcement or genuinely good environmental quality—the DiD framework addresses this ambiguity by controlling for city and year fixed effects, enabling a robust comparison of enforcement outcomes before and after the reform.

Using nationwide environmental penalty records available since 2003, we construct two measures for each city-year: the total number of penalties and the total fine amount in million yuan. We then estimate DiD regressions analogous to Equation 1, replacing bird diversity with these enforcement outcomes. As reported in Panel A of Table 4, the EPB reform was followed by substantial increases in enforcement activity. The number of penalties rose by 152.3%, and total fines increased by 144.6% relative to sample means. After deflating fines to 2003 values to control for inflation, the increase remains large at 142.6%.[26] These magnitudes demonstrate a meaningful tightening of environmental enforcement.

[26]In Table B4, where dependent variables are standardized, the reform increased penalty frequency and fine amounts by roughly 0.4 standard deviations.

[Insert Table 4 about here]

The event study parallel trends are depicted in Figure 6. As shown, the coefficients remain close to zero prior to the reform but increase sharply immediately afterward. The effects are particularly pronounced from years 0 to 2, indicating that officials responded strongly to the reform by enforcing penalties more rigorously once EPBs gained independence.

[Insert Figure 6 about here]

To verify whether stricter enforcement explains the biodiversity improvements documented earlier, we compare cities with different levels of penalty increases. Enforcement intensity is measured as the change in penalties from two years before the reform to the reform year. Cities with above-median increases are classified as "stricter", and those with below-median increases as "looser". Using the preferred specifications from Table 2, Panel B of Table 4 demonstrates that improvements in bird species richness and observation rates occur primarily in stricter cities. This finding confirms that variation in post-reform enforcement stringency plays an important role in driving the observed ecological effects.[27]

The granularity of the environmental penalty data allows us to scrutinize further how enforcement against different pollutant categories relates to biodiversity. Appendix A.5 analyzes the heterogeneous effects of enforcement on air, water, solid waste, and industrial noise violations, and documents how these dimensions differentially affect bird diversity.

The above results indicate that the EPB institutional reforms substantially tightened environmental enforcement, leading to a surge in fines imposed on firms. Although these fines represent a direct financial cost of non-compliance and thereby strengthen firms' incentives to comply, the fine amounts remain economically insignificant for most firms. On average, each penalty is about RMB 58,700 (approximately USD 8,260), a negligible share of operating revenue. The aggregate penalty amounts (RMB 4.93 million, or approximately USD 700,000, per city-year) also remain trivial relative to China's GDP.

[27] In Appendix Table B5, we use alternative years to define enforcement stringency. Panel A compares year 0 and year -1; Panel B compares year 1 and -1. The results are robust.

This motivates us to investigate whether, beyond the direct but negligible monetary cost, environmental penalties impose additional indirect costs on firms, thereby altering their incentives to engage in conservation efforts.

4.2 Reputation loss and indirect real costs

This section assesses the indirect reputational and economic costs of environmental penalties for firms. We start by compiling the subsample of environmental penalty events involving Chinese listed companies from 2003 to 2019.[28] The sample contains 2,320 penalty cases directly involving parent entities of listed firms and 8,937 cases when including penalties to their subsidiaries. This sample covers 618 unique listed companies (or 1,551 companies including subsidiaries), occurring in 1,199 days (or 1,837 days including subsidiaries). The regression analysis is restricted to firms that experienced at least one penalty during the sample period.

To examine reputational loss, we focus on an event window spanning five days before and after each penalty announcement ([-5, 5]). Using a comprehensive corpus of news articles, we compute for each firm-day the average sentiment score across all articles that primarily discuss the firm. The sentiment score ranges from -1 (most negative) to $+1$ (most positive). The regression adopts a difference-in-differences style empirical design, where the penalized firm serves as the treated entity with the treatment dummy denoted *Is penalized*, and non-penalized firms as controls. The *Post* dummy equals one for days following the penalty announcement (i.e., days [0, 5]).

Panel A of Table 5 presents the results. Penalized firms experience a significant decline in media sentiment following the penalty event, suggesting that both the media and the public pay attention to such incidents and respond negatively to environmental violations through unfavorable news coverage. They experience, on average, a 0.025-point drop in sentiment score. Moreover, this negative reaction is not limited to penalties imposed on the parent company; firms also experience reputational losses when their subsidiaries are penalized (columns 3–4).

[28] Environmental penalties are imposed on both listed and private firms in China. However, due to data limitations for private firms, this sub-section focuses primarily on listed firms and later sub-section extends the analysis to private firms using green patent data.

[Insert Table 5 about here]

At the same time, stock market reactions are negative. As shown in column 1 of Panel B, Table 5, the cumulative abnormal return (CAR) in the [-1, 3] and [-1, 5] day windows are -0.15% and -0.20%, respectively. This stock market effect is economically large.

This negative stock market reaction is justified by real adverse consequences from the financial and economic perspective. As shown in Panel C of Table 5, penalized firms see an increase in debt cost, a decrease in their market valuation (measured by Tobin's Q), a decline in institutional investor ownership, and a slowdown in annual sales growth in the penalty year. All the estimates are statistically significant and economically meaningful.

The findings underscore that strengthened enforcement has made environmental non-compliance costly for firms, largely beyond a direct fine. The drop in media sentiment and stock prices reflects the public's and the stakeholders' negative reaction to environmental violations. The increase in debt cost, declines in Tobin's Q and institutional ownership further indicate that investors downgrade their expectations of the firm's future prospects and may pull back funding, effectively raising the firm's financing costs (or at least limiting its access to capital) after an environmental infraction. These adverse consequences are justified by the hit to sales growth, which implies that firms face real economic costs in terms of lost revenue, potentially due to production disruptions (for instance, forced facility upgrades or temporary shutdowns) or weakened customer trust.

In sum, the EPB reform's stricter enforcement regime has substantially raised the expected cost of polluting, through both direct fines and indirect impacts on firm value and performance. This heightened cost of non-compliance is a crucial driver for the behavioral changes discussed next.

4.3 Corporate responses to stringent enforcement

This section starts by examining whether firms reduce pollution after being penalized, potentially due to requirements imposed by the environmental protection bureau and to avoid future fines. Panel A of Table 6 analyzes pollution behavior using self-reported emission data from listed firms. Column 1 estimates a difference-in-differences-style model over a $[-3, 3]$-year window around each penalty event, showing that penalized firms significantly reduce emissions after penalties.

[Insert Table 6 about here]

Next, we examine whether firms also respond to heightened risks of being penalized. Specifically, we test whether firms react to penalty events involving their peers. We consider two types of peers: industry peers (firms operating in the same industry) and city peers (firms located in the same city). Industry peers matter because penalties within the same sector are highly visible and may attract both public and regulatory attention to similar firms. City peers, by contrast, reflect the enforcement stringency of the local EPB. Note that this analysis does not rely on the EPB reform itself; rather, it captures firms' behavioral responses to perceived risks of penalty. Results in columns 2-3 show a negative, though statistically weaker, association between peer penalties and the focal firm's emissions, suggesting that a higher perceived risk of punishment deters pollution.

Column 4 focuses on the EPB reform as an exogenous shock that increased the likelihood of penalties. The result reveals that firms' average pollution declined by about 0.025 standard deviations post-reform. [29]

To understand how firms achieve emission reductions, we consider output cuts and technological improvements. Prior research suggests that Chinese firms primarily adopt cleaner technologies rather than reduce production (Liu et al., 2021; Huang and Lei, 2021).[30] We use green patent applications to capture environmental innovation and report the results in Panel B of Table 6. Penalized firms file about 0.152 more green patents annually within three years after receiving penalties—a substantial increase relative to the sample mean (0.31 patents applied per firm-year). Firms also innovate more after peers in the same industry or city are penalized. Finally, the EPB reform significantly boosts green innovation, as demonstrated in the staggered difference-in-differences framework.

In sum, the EPB vertical management reforms incentivized firms to internalize environmental costs and adopt greener practices. Stricter enforcement increased the expected,

[29] To ensure robustness, Appendix Table B7 presents results on the effects of penalties and the EPB reform on firm emissions, using four major pollutants: COD, NH_3–N, SO_2, and NO_x. The findings are consistent across individual pollutants.

[30] As indirect evidence that firms did not curtail output, the results in Appendix A.3 show that cities undergoing the reform experienced improved environmental quality without declines in local GDP. This suggests that stricter enforcement promoted pollution abatement without dampening economic activity. Given that local economic performance is largely driven by local firms, these findings imply that similar mechanisms likely operate at the firm level.

particularly indirect, costs of pollution, thereby motivating firms to reduce emissions through green technology upgrading. These findings underscore that stronger regulatory enforcement can effectively drive firms toward sustainable technological transformation, aligning corporate behavior with environmental objectives without constraining economic growth.

5 Local and Central Protectionism

In this section, we investigate which types of firms face increased penalties following the reform. This question is crucial because the EPB reforms likely created a new regulatory landscape for firms by increasing the potential of high-cost penalties. This heightened penalty risk could significantly impact firms' financial performance and behavior and, consequently, have implications for market assessment of firms' financial risks.

As introduced in Section 2.2, the EPB vertical management reform fundamentally aims to enhance administrative independence by reducing local government control. Drawing on the literature on judicial and administrative independence (e.g., Liu et al., 2022), we analyze the effects of the EPB reforms through the lens of protectionism, including both local and central protectionism.

5.1 Local protectionism

Local protectionism refers to the practice by which local governments favor businesses within their jurisdiction to stimulate economic growth, often resulting in leniency in regulatory enforcement of other sectors. This form of protectionism can arise because local governments rely on local firms for tax revenue, employment, and overall economic stability. As a result, local protectionism can undermine broader regulatory objectives, including environmental protection, by allowing firms to operate with reduced oversight. Local protectionism is evident in China. For instance, Liu et al. (2022) found that local courts favor local firms, which have higher win rates under conditions of judicial imperfection. In the environmental sector, Bai, Li, Xie, and Zhou (2021) reveal that city-level restrictions on used vehicle emissions did not significantly improve air quality and may have actually hindered market development and social welfare. This work highlights how local governments may engage in local protectionism under the pretense of environmental protection.

Within our context, local governments exercised leniency in enforcing environmental regulations prior to the EPB reforms, especially for local firms that significantly contributed to local tax revenue and were more likely to be politically connected to local government through various local networks. The reform aimed to increase the EPBs' administrative independence and reduce local protectionism, resulting in increased environmental penalties for these previously "protected" local enterprises. Therefore, we hypothesize that local firms are the major targets for paying increased fines.

In Panel A of Table 7, we replicate the analysis from Table 4 but divide the sample of sanctioned firms into local versus non-local firms. We identify a firm as local if its registration county is identical to the EPB county.[31] The results indicate that, post-reform, penalties were predominantly imposed on local firms. Neither the number of penalties nor the total fine amount imposed on non-local firms increased significantly after the reform.

[Insert Table 7 about here]

5.2 Central protectionism

Central protectionism occurs when firms with direct ties to the central government receive favorable treatment regardless of their geographical location. This protection can stem from the firm's political connections, strategic importance, or contribution to national economic objectives, often leading to selective enforcement of regulations. Central protectionism can limit the effectiveness of local and regional regulatory efforts by providing exemptions or reduced scrutiny to certain powerful firms. This problem is particularly severe in China's environmental sector (Wang et al., 2003; Hering and Poncet, 2014; Eaton and Kostka, 2017; Zhao, Jia, and Zhang, 2023). Centrally connected firms are typically state-owned enterprises (SOEs). As Eaton and Kostka (2017) document, Chinese SOEs receive substantial exemptions from environmental regulations yet were responsible for

[31] We identified the firms' registration locations for 68.79% of the penalty records. Among these identified cases, 84.22% of penalties were directed at local firms, while 15.78% were issued to non-local firms.

over 60% of reported environmental violations, a figure derived from compiled news reports across multiple media sources. In contrast, our environmental penalty database indicates a significant regulatory privilege: only 4.33% of penalty records were issued to SOEs.

We posit that SOEs are less likely to experience a significant increase in environmental penalties or associated costs following the EPB reforms, potentially due to their continued strong political link to the central government. In Panel B of Table 7, we replicate the analysis from Panel A of Table 4 but divide the sample into SOEs and privately owned enterprises (POEs). The results indicate that, post-reform, increased penalties are predominantly imposed on POEs.

In Appendix Figures B2 and B3, we plot the dynamic DiD coefficients for local versus non-local firms (Figures B2) and SOEs versus POEs (Figures B3). The sharp increase in penalties post-reform is clearly concentrated among local and privately owned firms.

Using the number of green patent applications at city-level as the dependent variable, we find significant increases in green patents among local firms, particularly local privately owned firms, following the EPB reforms (Panel C of Table 7). In contrast, SOEs do not show an increase in green patent investments.

The results are consistent with previous findings on protectionism, showing that only local privately owned firms face an increased penalty risk. In contrast, SOEs continue to benefit from central protectionism and leniency in enforcement, which reduces their incentive to invest in green initiatives. By examining the heterogeneous effects of environmental reform, we clarify the new costs imposed on different types of firms, with implications for financial assessments. Additionally, this analysis highlights the challenges of implementing conservation policies in politically connected, growth-oriented landscapes.

6 Conclusion

This paper demonstrates that strengthening the administrative independence of environmental regulators can materially enhance biodiversity. Leveraging comprehensive birdwatching records and the staggered rollout of China's Environmental Protection Bureau

(EPB) vertical management reform, we provide causal evidence that more autonomous enforcement agencies increase bird species richness and abundance on a substantial scale. These biodiversity gains arise alongside pronounced increases in environmental penalties, particularly in cities where enforcement intensity rose most sharply. Our findings reveal that the ecological benefits of environmental regulation depend not only on policy design but critically on the stringency and impartiality of enforcement.

Beyond documenting biodiversity outcomes, we uncover the mechanisms through which stricter enforcement influences firm behavior. Even though monetary fines remain modest, environmental penalties impose significant reputational and financial costs, including negative media sentiment, adverse stock market reactions, higher debt financing costs, reduced valuation, diminished institutional ownership, and slower sales growth. These indirect costs create strong incentives for firms to reduce pollution and invest in cleaner technologies. We show that firms respond not only to their own penalties but also to penalties issued to their peers, and that the EPB reform, by increasing the perceived probability of enforcement, induces firms to upgrade environmental technologies and expand green innovation. These results highlight the broader implications of environmental enforcement for corporate investment, risk pricing, and the allocation of resources toward sustainable production.

A final implication concerns government structure and regulatory equity. By reducing the influence of local governments, the reform curbed local protectionism and increased accountability for local and privately owned firms. Yet state-owned enterprises (SOEs), shielded by central protectionism, remained largely insulated from heightened scrutiny and did not increase their green innovation efforts. This asymmetric response underscores an important policy challenge: administrative independence improves enforcement outcomes but cannot fully overcome entrenched political privileges. Achieving equitable environmental accountability therefore requires complementary reforms aimed at reducing central protectionism.

Taken together, our findings offer several implications for biodiversity conservation, sustainable finance, and regulatory governance. First, conservation policies must prioritize not only the formulation of environmental rules but also the institutional arrangements that ensure credible, consistent, and impartial enforcement. Second, financial markets play a critical role in amplifying the cost of environmental violations, implying that market forces can serve as an important channel through which stronger enforcement drives real environmental improvements. Third, the unequal enforcement burden across firm types points to the need for governance reforms that align regulatory incentives with ecological objectives rather than political interests.

Overall, this study highlights that meaningful progress in biodiversity conservation requires more than expanding environmental legislation. It requires designing governance systems that strengthen administrative independence, reduce political distortions, and ensure that the true costs of environmental degradation are internalized by all firms.

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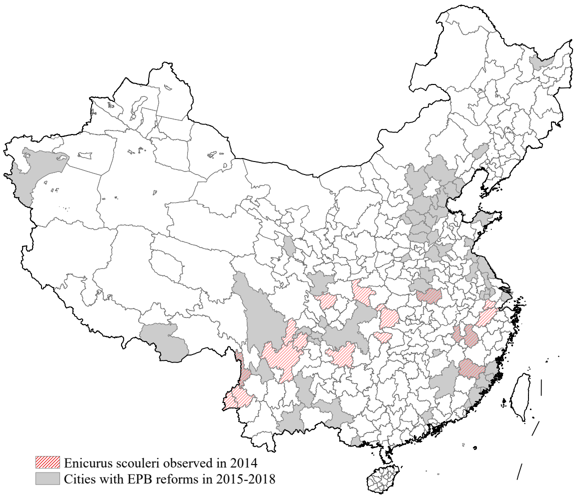
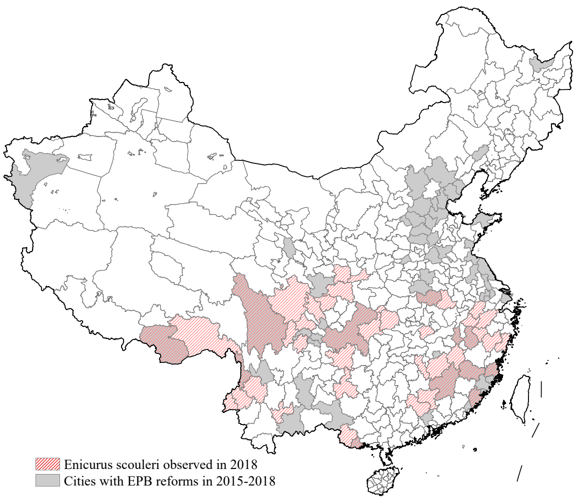
(a) Little Forktail (*Enicurus scouleri*)



(b) Cities with Little Forktail observed in 2014



(c) Cities with Little Forktail observed in 2018

Figure 1. **The expansion of Little Forktail (*Enicurus scouleri*) before and after reform.**

Notes: This figure illustrates the spatial distribution of the Little Forktail (*Enicurus scouleri*). Panel (a) features an image of the species, sourced from https://ebird.org/species/litfor1/IN-UL-PI. In Panels (b) and (c), shaded areas represent cities where the Little Forktail was observed in 2014 and 2018, respectively, while gray areas indicate cities that underwent EPB reform between 2015 and 2018 in both panels.

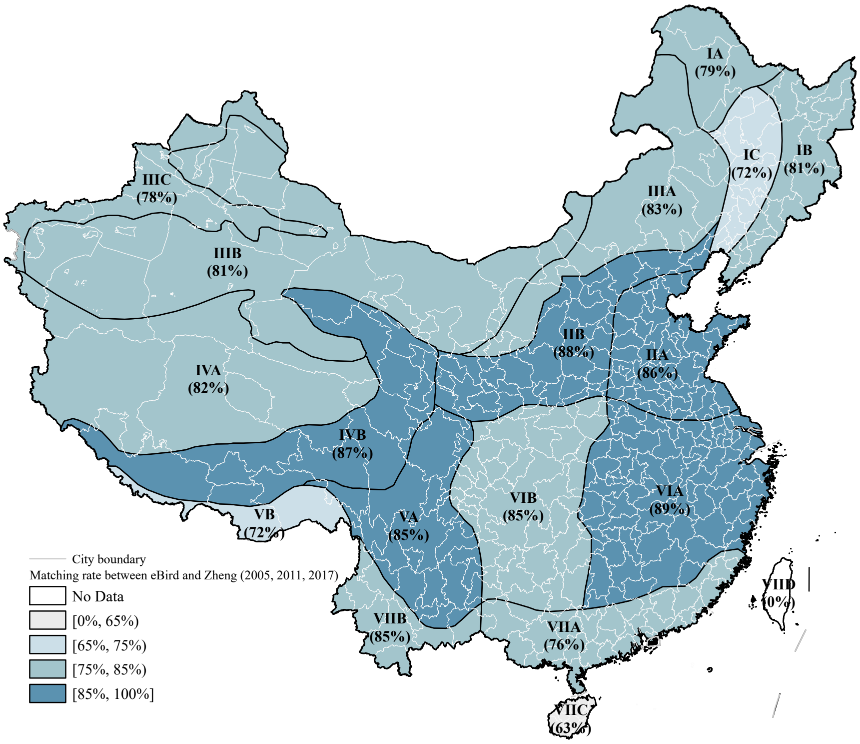


Figure 2. **Cross verification of bird distributions in zoogeographical regions.**

Notes: This figure illustrates the concordance between bird species distributions derived from birdwatching data and those documented in Zheng's monographs (Zheng, 2005, 2011, 2017). These monographs provide comprehensive lists of bird species and their occurrences across China's zoogeographical regions. For an in-depth explanation of these regions and access to the dataset from Zheng's works, please refer to Zhang et al. (2022). To assess the matching rate, we compiled two datasets for each zoogeographical region: 1) the complete list of bird species from Zheng's monographs, and 2) the list of species observed by *eBird.com* and *birdreport.cn* users. We then calculated the percentage of species in Zheng's list that were also reported by bird watchers. In the figure, these matching rates are presented in parentheses and are visualized by varying shades of blue, with darker hues indicating higher rates of concordance.

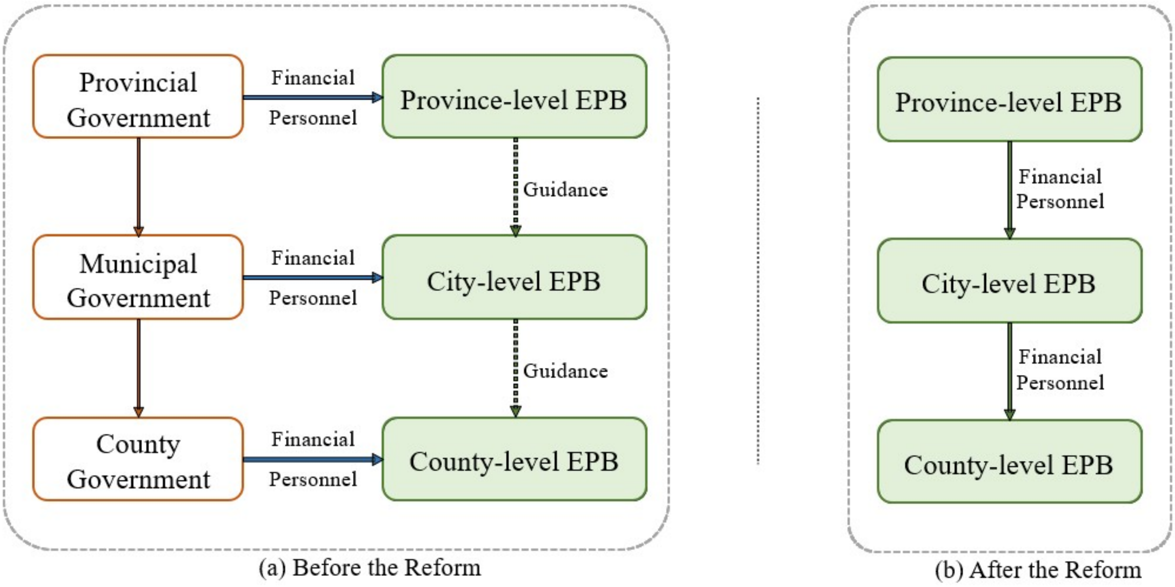
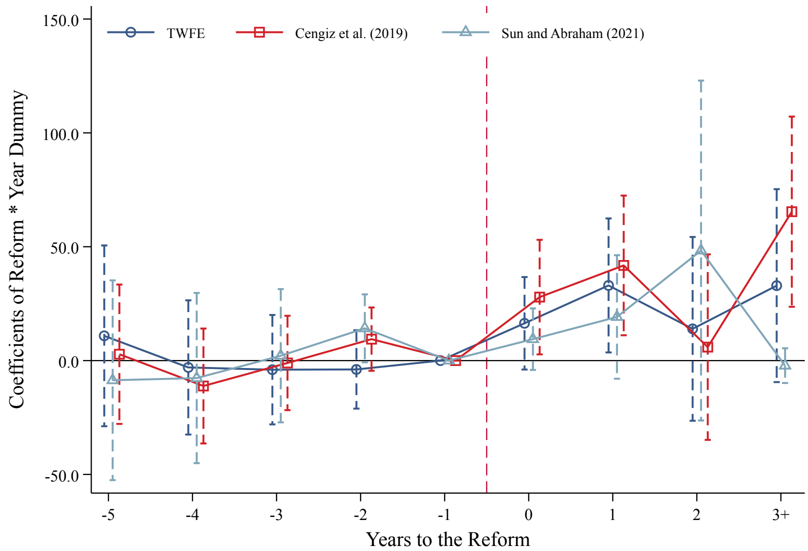


Figure 3. **Schematic diagram of EPB reforms.**

Notes: The figure illustrates the environmental system pre- and post-reform of a hypothetical Chinese city that supervises one county. In China, on average, each city has jurisdiction over 10 counties. The left panel depicts the system before the reform. In this pre-reform system, the county-level EPB was controlled by the county government while only nominally subordinated to the city-level EPB and receiving regulatory guidance from it. The right panel depicts the system after reform. The restructuring involved the city-level EPB assuming responsibility for the funding, staffing, and overall management of the county-level EPB.

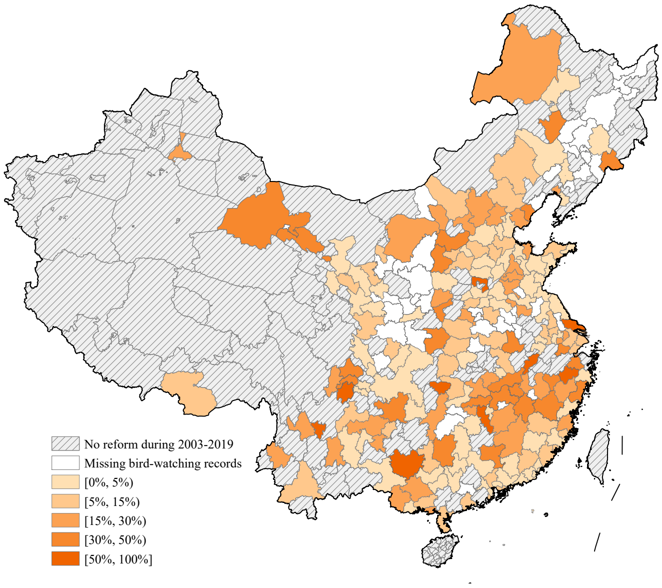
(a) Bird species



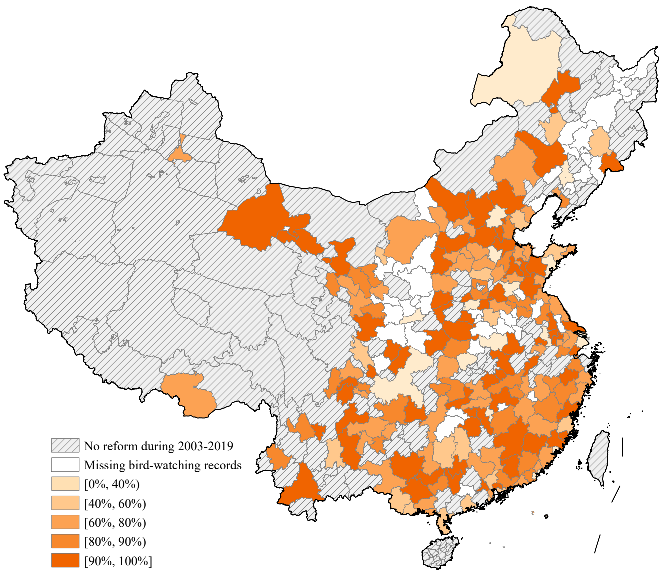
(b) Bird observation rate

Figure 4. **Parallel trends: the effects of EPB reforms on bird diversity.**

Note: This figure illustrates the pre- and post-trends in the effect of EPB reforms on bird diversity. The coefficients (with 95% confidence intervals) are derived from regressing the bird species (Panel a) and bird observation rate (Panel b) on relative-to-reform year dummies for the period between 2003 and 2019. We report estimates from a two-way fixed effects (TWFE) model, the stacked DiD approach (Cengiz et al., 2019), and the Sun and Abraham (2021) method. The year immediately preceding reform (year −1) serves as the reference period. "Year −5" denotes five years prior to reform, and "year 3" denotes three or more years post-reform. All regressions control for city-level and birdwatching event characteristics (see Table 2), as well as city and year fixed effects.



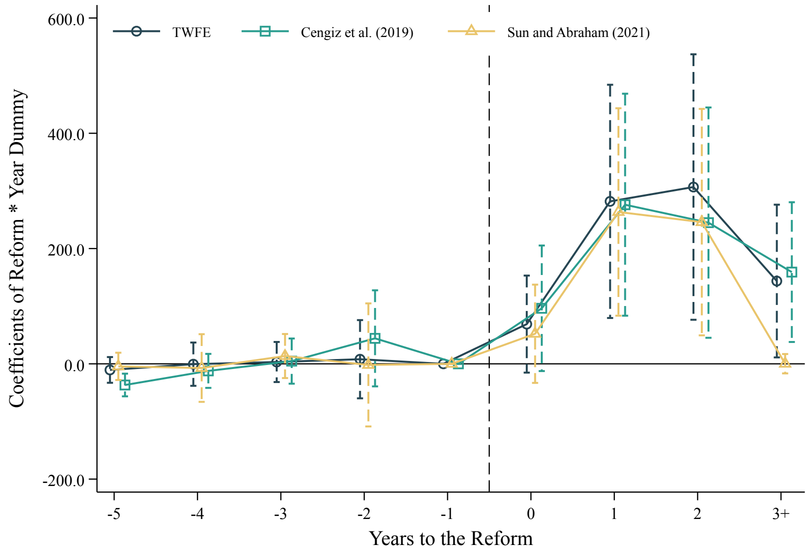
(a) Restoration ratio



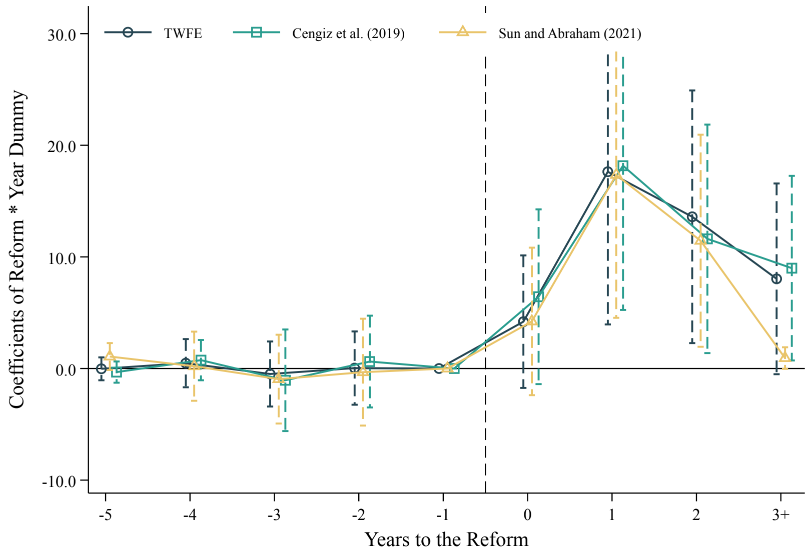
(b) Redistribution ratio

Figure 5. **Restoration and redistribution**

Note: This figure shows the city-level restoration ratio (Panel A) and redistribution ratio (Panel B). The restoration ratio is defined as the share of *reappeared species* among *new species*, where reappeared species are those observed in year [≤−4], absent in years [−3, −1], and reappearing in years [0, 2]. New species are those absent in [−3, −1] but present in [0, 2]. The redistribution ratio is defined as the share of *redistributed species* among *new species*, where redistributed species are those newly observed in the focal city but previously reported in neighboring cities. See Section 3.3 for details.



(a) Number of penalties



(b) Fine amount

Figure 6. **The effects of EPB reforms on penalties.**

Note: This figure shows the pre- and post-trends in the effect of EPB reforms on penalties. The coefficients (with 95% confidence intervals) are obtained from regressing the number of penalties (Panel a) and the total fine amount in million yuan (Panel b) on relative-to-reform year dummies for the period between 2003 and 2019. We report estimates from a two-way fixed effects (TWFE) model, the stacked DiD approach (Cengiz et al., 2019), and the Sun and Abraham (2021) method. The year immediately preceding reform (year −1) serves as the reference period. "Year −5" denotes five years prior to reform, and "year 3" denotes three or more years post-reform. All regressions control for city-level and bird-watching event characteristics (see Table 2), as well as city and year fixed effects.

Table 1. **Summary statistics of main variables**

Variable	**Obs.**	**Mean**	**S.D.**	**5%**	**Median**	**95%**
Independent variables, 2003–2019						
Post Reform (dummy)	4,709	0.12	0.32	0	0	1
Birdwatching (city–year), 2003–2019						
Bird species	1,586	73.03	77.38	3	46	226
Total # birdwatching events	1,586	27.80	118.00	1	5	106
Total effort hours	1,586	93.55	388.00	1.02	16.64	324.80
Birdwatching (event level), 2003–2019						
Bird observation rate (# per hour)	46,807	73.78	201.70	1.02	28.79	255.20
Effort hours per event	46,807	3.34	2.47	0.73	2.58	8.99
City–year controls, 2003–2019						
Population density (1,000 persons/sq.km)	4,625	0.95	0.94	0.12	0.72	2.65
Urbanization rate (%)	4,562	48.81	17.24	22.91	47.31	81.42
GDP (billion yuan)	4,614	108.70	260.50	5.55	35.17	424.60
Primary industry output (% of GDP)	4,613	7.03	6.71	0.71	4.81	20.77
Secondary industry (% of GDP)	4,613	48.74	12.38	27.59	48.77	68.27
Real estate investment (% of GDP)	4,486	14.15	9.75	3.49	11.96	31.58
Green space ratio (%)	4,574	3.82	5.39	0.20	2.11	12.07
Temperature (°C)	4,709	13.95	5.25	4	15.20	21.71
Precipitation (mm)	4,709	3.08	1.49	1.04	3.00	5.65
Wind speed (m/s)	4,709	1.02	0.37	0.51	0.97	1.68
Number of disasters	4,709	3.06	2.78	0	2	9
Enforcement (city–year), 2003–2019						
Number of penalties	4,709	84.10	322.60	0	0	414
Fine amount (million yuan)	4,709	4.93	17.58	0	0	25.70
Fine amount (million yuan, 2003=100)	4,709	3.35	11.83	0	0	17.27
Reputation (firm-day [-5, 5]), 2003–2019						
News sentiment	1,700,365	0.19	0.44	-0.71	0.08	0.91
News sentiment (incl. subsidiaries)	7,357,002	0.21	0.46	-0.72	0.09	0.92
Is penalized	192,173	0.01	0.10	0	0	0
Is penalized (incl. subsidiaries)	795,614	0.01	0.10	0	0	0
Real costs (firm-year), 2003–2019						
Debt cost (%)	17,321	-2.05	996.30	-22.84	3.97	10.38
Tobin's Q (%)	16,845	1.67	0.85	0.98	1.39	3.38
Institutional ownership (%)	26,367	3.91	7.86	0	0.07	21.36
Sales growth rate (%)	15,848	17.90	36.13	-23.76	12	75.39
Standardized emissions	33,296	0	0.85	-1.47	0.07	1.24
Number of green patents applied	2,635,289	0.31	1.05	0	0	2
Is penalized (incl. subsidiaries)	244,574	0.11	0.31	0	0	1
Is penalized, industry peer (incl. sub.)	217,610	0.63	0.48	0	1	1
Is penalized, city peer (incl. sub.)	217,610	0.54	0.50	0	1	1
Firm size	17,752	22.29	1.56	20.24	22.09	25.07
Leverage	17,752	0.54	1.54	0.15	0.51	0.83
ROA	17,791	0.04	0.21	-0.06	0.03	0.13
Firm age	24,667	13.88	7.34	2	14	26
Green patents (city–year), 2003–2019						
Number of green patents applied	4,709	253.50	571.10	1	43	1,528
Number of green patents applied, POE	4,709	10.09	27.75	0	0	64
Number of green patents applied, SOE	4,709	154.10	381	0	17	985

Refer to Appendix Table B2 for variable definitions.

Table 2. **Effects of EPB reforms on bird diversity**

This table examines the impact of Environmental Protection Bureau (EPB) reforms on bird diversity. We utilize two dependent variables to measure bird diversity. In columns 1–3, bird species refers to the total number of unique bird species observed in a city-year, with regressions at city-year level. In columns 4–7, bird observation rate is defined as the average number of birds observed per hour in each birdwatching event, with regressions at the event level. The key explanatory variable, post reform, is an indicator equal to one if the city has experienced EPB reform on or after year t. Control variables are added progressively throughout the analysis. City-level controls include population density, urbanization rate, GDP (log), industrial structure, the real estate investment-to-GDP ratio, green space ratio, average temperature, precipitation, wind speed, and number of disasters. We also control for available birdwatching covariates, including the number of birdwatching events and total effort hours. All regressions include city and year fixed effects. Column 7 further includes birdwatching account fixed effects. The sample comprises approximately 46,800 birdwatching events from 277 cities in China between 2003 and 2019 after filtering. City-years without any birdwatching activities are excluded. Standard errors clustered at the city level are reported in parentheses. Standard errors adjusted for arbitrary clustering to account for spatial correlation are reported in brackets (Colella et al., 2019). *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

	Bird species (at city-year level)			Bird observation rate (at event level)			
	1	2	3	4	5	6	7
Post reform	18.346	25.977	19.051	17.531	25.387	24.725	25.795
(SE)	(7.299)**	(7.528)***	(6.770)***	(10.863)	(11.307)**	(11.318)**	(9.669)***
[Colella SE]	[7.701]**	[8.008]***	[7.438]**	[11.275]	[11.827]**	[11.828]**	[9.682]***
Population density		4.149	4.149		-12.743	-12.615	-11.625
		(4.483)	(3.452)		(10.705)	(10.338)	(7.657)
Urbanization rate		-1.448*	-0.486		0.312	0.211	-0.218
		(0.848)	(0.611)		(0.879)	(0.838)	(0.611)
GDP (log)		38.754***	34.003***		-25.529	-24.958	-0.412
		(14.496)	(12.194)		(30.706)	(29.744)	(19.673)
Primary ind. output/GDP		1.460	0.795		-7.118	-6.926	-5.193
		(2.086)	(1.705)		(4.541)	(4.500)	(4.140)
Secondary ind. output/GDP		-0.454	-0.389		0.731	0.701	-0.873
		(0.494)	(0.424)		(1.346)	(1.328)	(0.835)
Real-estate inv./GDP		-0.256	-0.019		-0.263	-0.250	-0.326
		(0.338)	(0.255)		(0.902)	(0.889)	(0.385)
Green space ratio		0.991	0.467		-0.392	-0.272	0.208
		(1.147)	(0.710)		(1.429)	(1.388)	(0.997)
Temperature		0.928	0.609		-15.725**	-16.108**	-11.395
		(4.843)	(4.219)		(7.546)	(7.628)	(8.332)
Precipitation		0.029	-0.796		4.665	5.042	7.081*
		(2.601)	(2.183)		(5.145)	(5.116)	(4.014)
Wind speed		-7.470	-9.582		12.998	10.034	-31.009*
		(14.740)	(13.370)		(25.138)	(24.898)	(18.688)
Number of disasters		0.148	0.502		-3.229***	-3.171***	-2.164**
		(0.791)	(0.675)		(1.206)	(1.204)	(0.906)
Total # birdwatching events			-0.046				
			(0.294)				
Total effort hours			0.083				
			(0.082)				
Effort hours of the event						-3.427***	-1.450
						(1.101)	(1.374)
City and Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birdwatching account FE							Yes
R-squared	0.698	0.712	0.776	0.150	0.151	0.152	0.257
Observations	1,576	1,422	1,422	46,805	41,074	41,074	40,267

Table 3. **Species heterogeneity**

This table examines the heterogeneous effects of EPB reforms on bird diversity across endangered vs. non-endangered species (Panel A) and migrant vs. resident species (Panel B). Columns 1 and 3 report results for bird species, while columns 2 and 4 report results for bird observation rate. The model specifications follow those in columns 3 and 6 of Table 2, except that the dependent variables are split by species category. All regressions include city and year fixed effects. Standard errors are clustered at the city level and reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Endangered vs. non-endangered birds

	Endangered species		Non-endangered species	
	Bird species	Bird obs. rate	Bird species	Bird obs. rate
	1	2	3	4
Post reform	3.115**	21.800**	16.227***	11.832*
	(1.283)	(9.895)	(5.905)	(6.465)
City and birdwatching controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.767	0.179	0.770	0.133
Observations	1,051	18,401	1,412	40,675
Mean of dependent var.	8.87	17.94	66.87	65.68

Panel B. Migrant vs. resident birds

	Migrant species		Resident species	
	Bird species	Bird obs. rate	Bird species	Bird obs. rate
	1	2	3	4
Post reform	12.338**	24.229**	5.654**	0.963
	(4.836)	(11.409)	(2.607)	(1.545)
City and birdwatching controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.778	0.151	0.754	0.102
Observations	1,407	40,131	1,368	37,699
Mean of dependent var.	48.19	54.25	26.44	21.07

Table 4. **EPB reforms, enforcement stringency, and bird diversity**

Panel A of this table explores the impact of Environmental Protection Bureau (EPB) reforms on environmental penalties conducted by local EPBs. We utilize three dependent variables to measure environmental penalties: the number of penalties, the total fine amount (in million yuan), and the total fine amount deflated to the year 2003 (in million yuan). Model specifications are identical to columns 1 and 2 of Table 2. The analysis encompasses 277 cities from 2003 to 2019 in China. Panel B presents a subsample analysis to verify that improvements in biodiversity are driven by stricter enforcement of environmental laws following the EPB reforms. Cities are categorized into "stricter" and "looser" based on the intensity of changes in enforcement, specifically the difference in penalties between reform year (0) and two years pre-reform (-2). "Stricter" cities are those above the median in penalty increases, while "looser" cities fall below the median. Model specifications follow columns 3 and 6 of Table 2. Both subsamples encompass around 113 cities from 2003 to 2019 in China. The *Diff p-values* refer to the p-value of the SUEST test, which compares the coefficients across different models. Standard errors are clustered at the city level and are reported in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

Panel A. Environmental penalties

	Number of penalties		Total fine amount		Total fine (deflated)	
	1	2	3	4	5	6
Post reform	159.767***	128.061**	7.800**	7.127**	5.216**	4.776**
	(55.077)	(54.996)	(3.240)	(3.487)	(2.162)	(2.325)
City controls		Yes		Yes		Yes
City and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.405	0.430	0.414	0.418	0.416	0.419
Observations	4,709	4,360	4,709	4,360	4,709	4,360

Panel B. Enforcement stringency and bird diversity

	Bird species		Bird observation rate	
	Stricter	Looser	Stricter	Looser
	1	2	3	4
	Diff p-value: 0.037		*Diff p-value: 0.055*	
Post reform	27.372***	7.775	49.515**	6.120
	(9.487)	(7.212)	(19.123)	(10.590)
City controls	Yes	Yes	Yes	Yes
Birdwatching controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.792	0.795	0.155	0.154
Observations	702	712	20,323	20,643

Table 5. **Reputation loss and indirect real costs**

This table examines the effects of environmental penalties on penalized firms. Panel A focuses on reputational loss. The dependent variable is the average news sentiment toward each firm within a [−5, 5] day window around the penalty announcement (stacked across events). The key independent variable is the interaction between an *Is penalized* dummy (equal to one if the parent entity of the firm is penalized) and a *Post* dummy (equal to one for the post-penalty period, i.e., days [0, 5]). *Is penalized (incl. subsidiaries)* equals one if the parent entity or any subsidiary of the listed firm is penalized. The sample includes all listed firms that were penalized at least once during 2003–2019. Firm and day fixed effects are included, and standard errors are clustered at the firm level. Panel B focuses on short-term market reactions. The variable of interest is the cumulative abnormal returns (CAR) over [−1, 3] and [−1, 5] windows, estimated using the CAPM model and reported in percentages. Panel C examines the indirect real costs of penalties. The dependent variables include Debt cost, Tobin's Q, Institutional ownership, and Sales growth, defined in Table B2. The key independent variable equals one if the firm (parent entity or any subsidiaries) is penalized in that year. Firm and year fixed effects are included, and standard errors are clustered at the firm level. Standard errors are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Reputation loss

	News sentiment score, daily within event window [-5,5]			
	1	2	3	4
Is penalized × Post	-0.024**	-0.025**		
	(0.010)	(0.011)		
Is penalized (incl. subsidiaries) × Post			-0.005	-0.010*
			(0.005)	(0.005)
Firm size		0.020**		0.042***
		(0.009)		(0.007)
Leverage		-0.093*		-0.153***
		(0.047)		(0.037)
ROA		0.493***		0.216***
		(0.133)		(0.081)
Firm age (log)		-0.020		-0.052
		(0.093)		(0.060)
City controls		Yes		Yes
Firm and day FE	Yes	Yes	Yes	Yes
R-squared	0.130	0.138	0.125	0.130
Observations	1,700,319	1,408,794	7,356,969	6,014,537

Panel B. CAR

	Obs	Mean	S.D.	t-stat	p-value
CAR $[-1, 3]$	8,407	-0.150**	5.890	-2.340	0.019
CAR $[-1, 5]$	8,395	-0.196**	7.421	-2.420	0.016

Panel C. Indirect real costs

	Debt cost	Tobin's Q	Institutional ownership	Sales growth
	1	2	3	4
Is penalized (incl. subsidiaries)	52.555*	-0.041**	-0.518***	-3.127***
	(31.445)	(0.017)	(0.174)	(0.895)
Firm controls	Yes	Yes	Yes	Yes
City controls	Yes	Yes	Yes	Yes
Firm and Year FE	Yes	Yes	Yes	Yes
R-squared	0.279	0.600	0.352	0.180
Observations	14,890	14,525	15,289	13,618

Table 6. **Penalties, green initiatives, and spillover**

This table examines whether firms respond to environmental penalties and to the perceived heightened risk of being penalized. In Panel A, the dependent variable, Standardized emissions (z-score), is the average z-score of all available emission indicators (see Table B2 for detailed definitions). Columns 1–3 use a stacked event-window design, where the sample includes firm-years within a [−3, +3] window around each penalty event. In column 1, the key independent variable is the interaction between an *Is penalized (incl. sub.)* dummy (equal to one when the listed firm or any of its subsidiaries is penalized in that year) and a *Post* dummy (equal to one for post-penalty years [0, 3]). Columns 2–3 examine firms' responses to penalties imposed on their peers; penalized firms are excluded, and the treatment indicator equals one for firms in the same industry (column 2) or the same city (column 3) as the penalized firm. Column 4 estimates the effect of the EPB reforms following the baseline DiD design in Table 2. Firm-level controls follow Table 5. Panel A includes all listed firms that were penalized at least once between 2003 and 2019. In Panel B, the dependent variable is the number of green patent applications per firm-year, and the independent variables are identical to those in Panel A. This panel includes both listed and unlisted firms. All regressions include firm and year fixed effects. Standard errors are clustered at the firm level and reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Emission

	Standardized emissions (z-score)			
	1	2	3	4
Is penalized (incl. sub.) × Post	-0.008***			
	(0.003)			
Is penalized, industry peer (incl. sub.) × Post		-0.002		
		(0.002)		
Is penalized, city peer (incl. sub.) × Post			-0.003*	
			(0.002)	
Post reform				-0.025***
				(0.009)
Firm controls	Yes	Yes	Yes	Yes
City controls	Yes	Yes	Yes	Yes
Firm and year FE	Yes	Yes	Yes	Yes
R-squared	0.947	0.950	0.950	0.948
Observations	77,135	63,644	63,644	25,714

Panel B. Green patent applications

	# green patents applied			
	1	2	3	4
Is penalized (incl. sub.) × Post	0.152***			
	(0.013)			
Is penalized, industry peer (incl. sub.) × Post		0.008***		
		(0.002)		
Is penalized, city peer (incl. sub.) × Post			0.010***	
			(0.003)	
Post reform				0.022***
				(0.005)
City controls	Yes	Yes	Yes	Yes
Firm and year FE	Yes	Yes	Yes	Yes
R-squared	0.458	0.422	0.422	0.395
Observations	1,319,320	1,211,089	1,211,089	2,408,329

Table 7. **Local and central protectionism**

This table examines heterogeneous effects of the EPB reforms on environmental penalties and green initiatives through the lens of local versus central protectionism. In Panel A, firms are split into local versus non-local, where a firm is classified as local if its registration county matches the enforcing EPB's county. In Panel B, firms are split into state-owned enterprises (SOEs) versus privately owned enterprises (POEs). Model specifications follow columns 2 and 4 of Panel A in Table 4. Panel C uses as the dependent variable the total number of green patent applications filed by local firms in a city-year. The sample comprises 277 cities from 2003–2019. *Diff p-values* report SUEST tests of coefficient equality across the paired subsamples. Standard errors are clustered at the city level and are reported in parentheses. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Panel A. Local protectionism

	Number of penalties		Total fine amount	
	Local firms	Non-local firms	Local firms	Non-local firms
	1	2	3	4
	Diff p-value: 0.001		*Diff p-value: 0.052*	
Post reform	116.384**	-5.003	5.069*	-0.181
	(47.615)	(7.766)	(2.806)	(0.608)
City controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.383	0.313	0.331	0.242
Observations	4,360	4,360	4,360	4,360

Panel B. Central protectionism

	Number of penalties		Total fine amount	
	SOEs	POEs	SOEs	POEs
	1	2	3	4
	Diff p-value: 0.023		*Diff p-value: 0.033*	
Post reform	0.969	127.099**	-0.246	7.376**
	(3.212)	(52.921)	(0.267)	(3.384)
Controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.340	0.430	0.209	0.415
Observations	4,360	4,360	4,360	4,360

Panel C. Protectionism and green patents

	# green patents applied		
	All (local) firms	SOEs	POEs
	1	2	3
		Diff p-value: 0.091	
Post reform	102.962*	1.359	71.951*
	(54.920)	(2.892)	(42.018)
City controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
R-squared	0.714	0.663	0.657
Observations	4,360	4,360	4,360

Appendices for
From Fines to Feathers: Enforcement Stringency, Protectionism, and Biodiversity

Appendix A Additional results

Appendix A.1 Robustness tests

This section presents a series of robustness checks for the baseline results. Specifically, we re-examine the effects of the EPB reforms on bird diversity using alternative filtering criteria, varying sample periods, and additional control variables.

A.1.1. Relaxing and tightening effort hour thresholds

First, we revisit the filtering criterion. As noted in Section 2.1, birdwatching checklists are submitted by amateurs, and there is an inherent trade-off between preserving raw data and excluding outliers. In the baseline, we exclude events shorter than 0.5 hour or longer than 12 hours, a choice supported by Appendix Table B1. In this section, we relax the filter (retaining events between 0.25 and 24 hours) and tighten it (retaining events between 1 and 8 hours). As shown in Appendix Table A1, the results remain robust. Moreover, comparing Table 2 and Appendix Table A1, the estimated effects of EPB reform on bird diversity increase monotonically as the filter becomes stricter. Conditional on the same sets of covariates, under the 0.25–24, 0.5–12 (baseline), and 1–8 hour window, post-reform bird species rose by 19.10%, 26.09% and 30.84%, and bird abundance increased by 30.88%, 34.96% and 47.32%, respectively.

A.1.2. Accounting for observer ability

Second, we address the potential concern of observer ability. Checklists submitted by inexperienced amateurs may bias the results, potentially through misidentifying bird species or underestimating bird abundance (failing to detect hidden birds). To mitigate this, we exclude the first checklist submitted by each observer (as identified by account ID), thereby restricting the sample to individuals who have submitted at least two checklists and excluding one-time observers. As shown in Appendix Table A2, the results remain robust, with little change in magnitude. Additionally, in Appendix Table A3, we further restrict the sample to *eBird.com* checklists only, which allows us to control for the number of observers per event and effort distance. These additional controls account more directly for birdwatching effort and observer ability, and the results remain robust.

A.1.3. Alternative sample periods

Third, we conduct a robustness analysis using an alternative sample period between

2014 and 2019. Since 2014, birdwatching records increased significantly, likely due to the growing popularity of birdwatching in China and the launch of *birdreport.cn* online in 2014. Additionally, the majority of cities (215 of 277) underwent EPB reforms between 2014 and 2019. As shown in Appendix Table A4, the estimated effects of EPB reforms on bird diversity and bird observation rate remain robust within this short window.

A.1.4. Addressing the confounding effects of environmental courts

One may be concerned that the EPB reform may not be the primary driving factor behind our findings, especially considering the concurrent establishment of environmental courts. Zhang, Yu, and Kong (2019) found that the staggered establishment of environmental courts in Chinese cities spurred firms' environmental investment.[32] In Appendix Table A5, we conduct a horse-race test by including an indicator for the presence of an environmental court. The results show that the estimated effects of the EPB reforms remain highly robust. Environmental courts are associated with increases in bird diversity but show no significant effect on the bird observation rate.

[32] Zhang et al. (2019) argue that environmental courts increase firms' environmental investment by enhancing judicial efficiency. With the courts in place, citizens can more easily sue polluting firms, and cases are adjudicated more fairly, which in turn strengthens the administrative capacity of EPBs. However, their paper does not directly address the enforcement incentives or stringency of local EPBs; while courts make it easier for EPBs to enforce penalties once fines are issued, they do not fundamentally change the incentives of local EPBs to monitor firms.

Table A1. **Alternative filtering criteria**

This table replicates columns 3, 6 and 7 of Table 2, but applies alternative data-filtering criteria. In the baseline (Table 2), we exclude birdwatching events with effort hours less than 0.5 hour or greater than 12 hours. In this table, Panel A adopts a looser filter, excluding events with effort hours below 0.25 hour or above 24 hours. Panel B adopts a stricter filter, excluding events with effort hours below 1 hour or above 8 hours. Standard errors clustered at the city level are reported in parentheses. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Panel A. Looser filter (0.25-24h)

	Bird species (city-year level)	Bird observation rate (event level)	
	1	2	3
Post reform	14.328***	20.998**	23.133**
	(6.824)	(10.469)	(9.409)
Controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
Birdwatching account FE			Yes
R-squared	0.785	0.151	0.260
Observations	1,474	43,978	43,110
Mean of dep. var.	75.03	74.91	74.91

Panel B. Stricter filter (1-8h)

	Bird species (city-year level)	Bird observation rate (event level)	
	1	2	3
Post reform	21.334***	35.354**	33.815***
	(6.536)	(15.330)	(12.619)
City and birdwatching controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
Birdwatching account FE			Yes
R-squared	0.777	0.171	0.278
Observations	1,319	33,203	32,420
Mean of dep. var.	69.18	71.46	71.46

Table A2. **Experienced observers**

This table replicates column 3, 6 and 7 of Table 2 except that the sample exclude the first checklist submitted by each observer (as identified by account ID), thereby restricting the sample to individuals who have submitted at least two checklists and excluding one-time observers. Standard errors clustered at the city level are reported in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	Bird species (city-year level)	Bird observation rate (event level)	
	1	2	3
Post reform	20.060***	26.363**	27.257***
	(7.023)	(11.738)	(9.964)
City and birdwatching controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
Birdwatching account FE			Yes
R-squared	0.773	0.154	0.255
Observations	1,367	38,801	38,359
Mean of dep. var.	73.21	75.11	75.11

Table A3. **eBird sample with more controls**

This table focuses on the *eBird.com* sample, which allows us to control for the number of observers per event and effort distance. Columns 1 and 3 replicate Columns 1 and 2 of Table 2, but restrict the sample to *eBird.com* checklists only and exclude the first checklist submitted by each observer (as identified by account ID). Columns 2, 4, and 5 additionally include controls for effort distance and the number of observers. Standard errors clustered at the city level are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

	Bird species (city-year level)		Bird observation rate (event level)		
	1	2	3	4	5
Post reform	28.566***	21.434***	39.508*	39.157*	47.146*
	(7.153)	(6.380)	(23.543)	(23.693)	(25.847)
Total # observers		-0.019			
		(0.048)			
Total effort distance		0.005			
		(0.042)			
# observers of the event				0.554	-0.132
				(1.006)	(0.752)
Effort distance of the event				1.760**	1.693*
				(0.780)	(0.913)
City controls	Yes	Yes	Yes	Yes	Yes
Birdwatching controls	Yes	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes	Yes
Birdwatching account FE					Yes
R-squared	0.708	0.775	0.151	0.152	0.279
Observations	1,076	1,076	20,620	20,620	20,138
Mean of dep. var.	63.63	63.63	101.30	101.30	101.30

Table A4. **Alternative sample, 2014-2019**

This table replicates column 3, 6 and 7 of Table 2, but restricts the sample to 2014–2019. Standard errors clustered at the city level are reported in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	Bird species (city-year level)	Bird observation rate (event level)	
	1	2	3
Post reform	13.577**	22.888*	26.383**
	(5.898)	(11.671)	(10.774)
City and birdwatching controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
Birdwatching account FE			Yes
R-squared	0.867	0.154	0.259
Observations	945	38,037	37,295
Mean of dep. var.	87.93	74.57	74.57

Table A5. **Horse race: Environmental courts**

This table examines the role of environmental courts. Columns 1, 3, and 4 replicate Columns 3, 6, and 7 of Table 2, but additionally control for a dummy indicating whether an environmental court was established in the city. Columns 2 and 5 report the independent effects of environmental courts on bird diversity. Standard errors clustered at the city level are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

	Bird species (city-year level)		Bird observation rate (event level)		
	1	2	3	4	5
Post reform	17.943***		24.383**	26.161***	
	(6.768)		(10.993)	(9.538)	
Enviromental court	15.320**	16.170**	5.011	-6.708	8.327
	(6.868)	(6.956)	(11.032)	(9.078)	(11.900)
City and birdwatching controls	Yes	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes	Yes
Birdwatching account FE	Yes	Yes		Yes	Yes
R-squared	0.778	0.776	0.152	0.257	0.152
Observations	1,422	1,422	41,074	40,267	41,074

Appendix A.2 Assessing potential endogeneity in reform timing

Another potential concern in our setting is the endogeneity of the EPB reform adoption timing. To the best of our knowledge, anecdotally there is no single, uniform criterion that determines when each city adopts the reform. According to a few available government documents, within each province, the reform was first piloted in selected cities and subsequently expanded to others. The order of adoption was likely influenced by various economic and political considerations. A concern, however, is that if adoption were systematically driven by deteriorating biodiversity prior to the reform, reverse causality could bias our estimates. To examine this possibility, we estimate a survival (hazard) model (Acharya, Baghai, and Subramanian, 2014). As reported in Appendix Table A6, lagged measures of bird species and bird population do not predict the timing of reform adoption. This evidence supports the validity of our DiD identification strategy.

Table A6. **Survival model on reform timing**

This table applies the survival (hazard) model (Acharya et al., 2014) and examines whether biodiversity and economic variables could predict the timing of EPB reform adoption. All variables are lagged one period. Standard errors clustered at the city level are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

	1	2
Bird species	0.001	
	(0.201)	
Bird observation rate		-0.001
		(0.189)
Population density	0.071	0.051
	(0.347)	(0.488)
Urbanization rate	-0.011*	-0.012*
	(0.075)	(0.064)
GDP (log)	0.197*	0.241**
	(0.072)	(0.020)
Primary ind. output / GDP	0.008	0.006
	(0.599)	(0.701)
Secondary ind. output / GDP	-0.004	-0.005
	(0.543)	(0.489)
Real estate investment / GDP	-0.006	-0.005
	(0.308)	(0.368)
Green space ratio	-0.004	-0.002
	(0.734)	(0.876)
Temperature	-0.003	-0.007
	(0.900)	(0.772)
Precipitation	-0.089	-0.070
	(0.274)	(0.356)
Wind speed	-0.033	0.011
	(0.848)	(0.950)
Number of disasters	0.062	0.068
	(0.178)	(0.145)
Total # birdwatching events	-0.005	-0.007**
	(0.165)	(0.031)
Total effort hours	0.001	0.002**
	(0.201)	(0.031)
Observations	1,094	1,094
χ^2	24.69	25.06

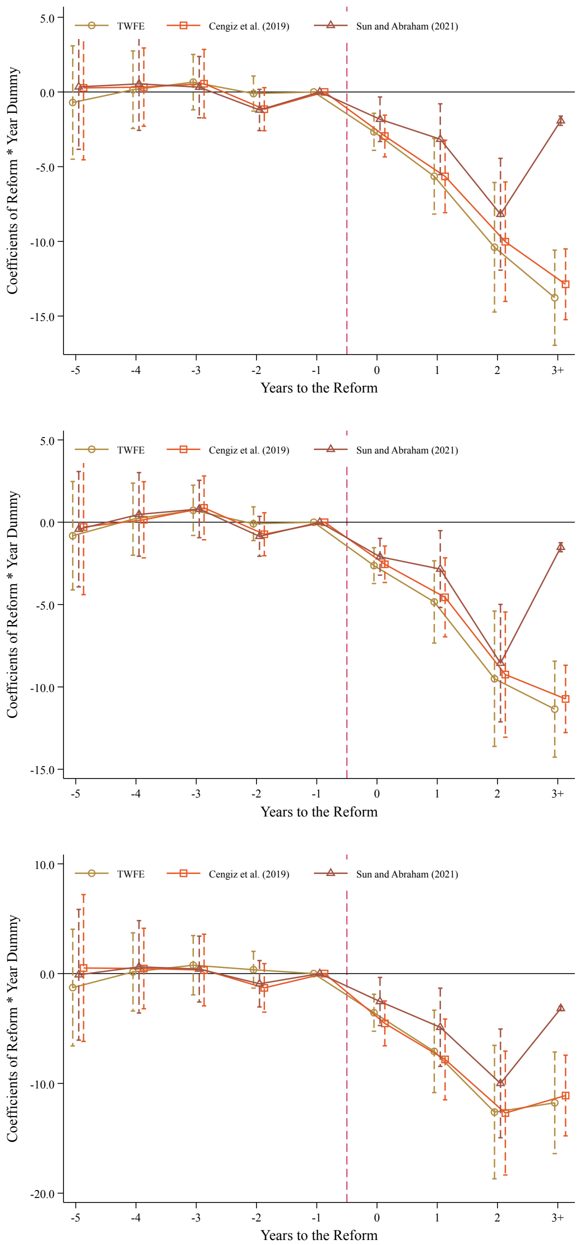
Appendix A.3 EPB reforms, pollution, and economic output

While we have shown that EPB reforms improved biodiversity in Section 3, the underlying channel must operate through environmental improvement. In this section, we examine whether EPB reforms led to reductions in pollution.

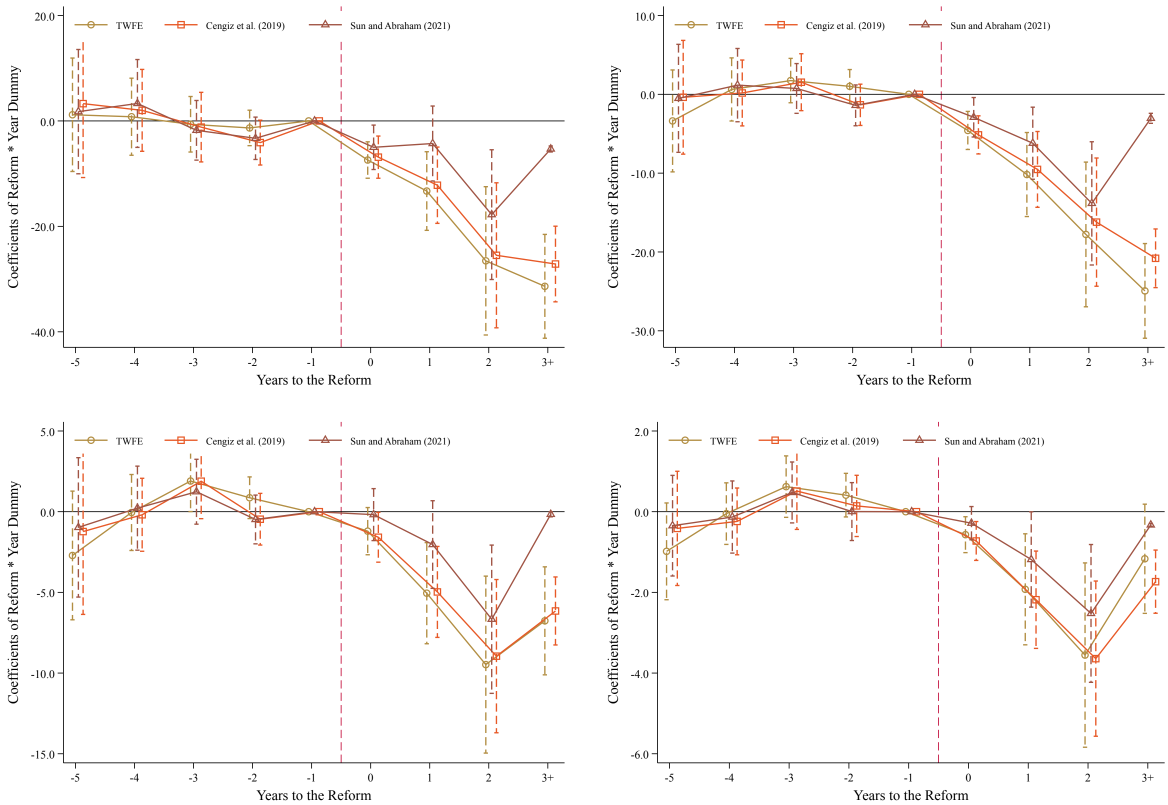
We compile city-level emissions data from multiple official sources. We begin by evaluating air quality improvements associated with the EPB reform (Appendix Figure A1 and Table A7). Using the Air Quality Index (AQI) as well as PM2.5 and PM10 concentrations, we find that the reform is associated with significant reductions in all three indicators. Moreover, the number of pollution days per year also declines following the reform. We further examine aggregate city-level emissions data reported in municipal yearbooks (Appendix Figure A2 and Table A8) and document decreases in wastewater discharge, sulfur dioxide (SO_2), and soot emissions, particularly after 2014, when most EPB reforms were implemented.

An extended question is whether the reduced emissions were driven by reduced economic output in response to more stringent environmental enforcement. We rely on city-level proxies, in particular GDP, to approximate output. Our analysis (Appendix Table A9) shows that overall city-level output did not decrease following the reform, suggesting that the reform did not negatively impact economic activities at the city level.[33]

[33] We acknowledge that our findings, specifically that GDP remains unaffected, may align well with the EPB reform but may not necessarily apply to other policies aimed at reducing pollution in China. Chen, Li, and Lu (2018) found that when local officials' performance evaluations were adjusted in 2005 to emphasize environmental targets, GDP growth slowed due to officials' career-related incentives. We argue that officials may prioritize environmental improvements, even at the expense of economic output, when such targets are set as key performance indicators. However, the EPB reforms emphasize the administrative independence of environmental departments, which should have a comparatively lower impact on economic growth.



(a) Panel A. Air quality: AQI, PM2.5 and PM10



(b) Panel B. Pollution days: slight, median, heavy and severe

Figure A1. **Effects of EPB reforms on city-level pollution: Air quality**

Note: This figure shows the pre- and post-trends in the effect of EPB reforms on air quality, measured by air pollutants (Panel A) and the number of pollution days in a year (Panel B). The coefficients (with 95% confidence intervals) are obtained from regressing the dependent variables on relative-to-reform year dummies for the period between 2003 and 2019. We report estimates from a two-way fixed effects (TWFE) model, the stacked DiD approach (Cengiz et al., 2019), and the Sun and Abraham (2021) method. The year immediately preceding reform (year −1) serves as the reference period. "Year −5" denotes five years prior to reform, and "year 3" denotes three or more years post-reform. All regressions control for city-level and birdwatching event characteristics (see Table 2), as well as city and year fixed effects.

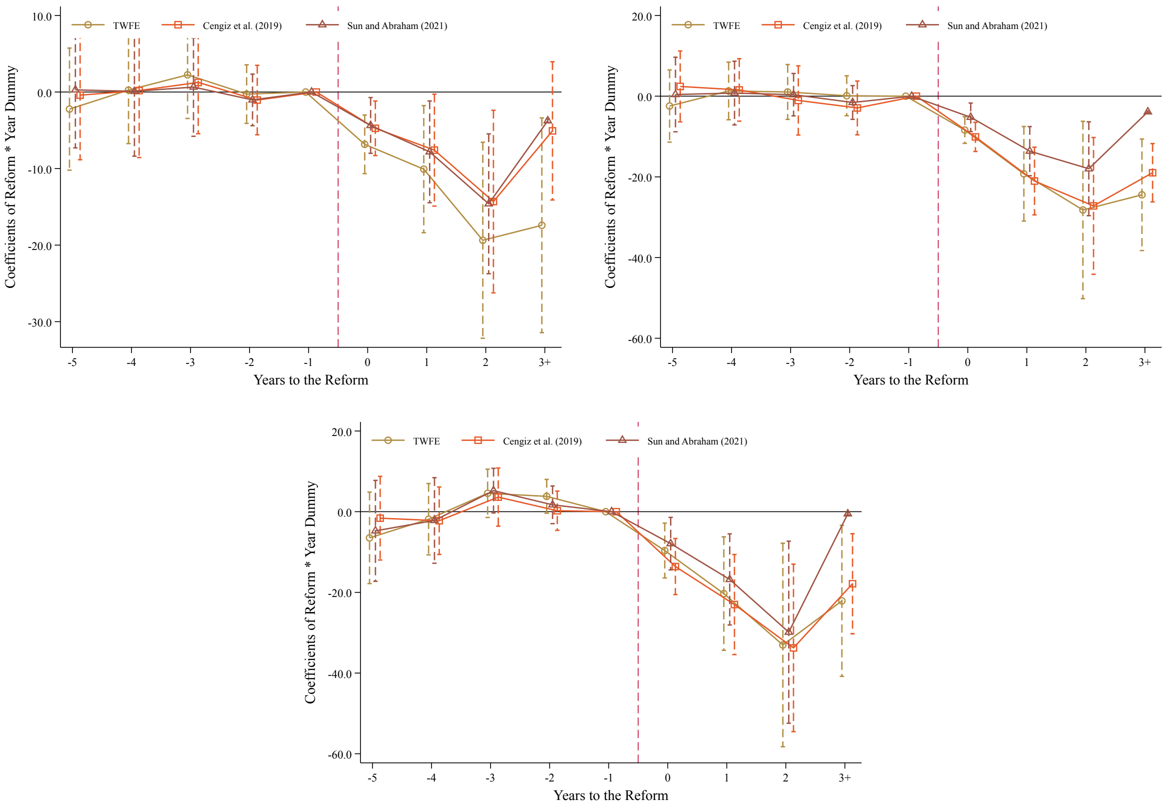


Figure A2. **Effects of EPB reforms on city-level pollution: pollutants (2014-2019)**

Note: This figure shows the pre- and post-trends in the effect of EPB reforms on pollutants, including Waterwaste, SO2, and NO_x. The coefficients (with 95% confidence intervals) are obtained from regressing the dependent variables on relative-to-reform year dummies for the period between 2014 and 2019. We report estimates from a two-way fixed effects (TWFE) model, the stacked DiD approach (Cengiz et al., 2019), and the Sun and Abraham (2021) method. The year immediately preceding reform (year -1) serves as the reference period. "Year -5" denotes five years prior to reform, and "year 3" denotes three or more years post-reform. All regressions control for city-level and birdwatching event characteristics (see Table 2), as well as city and year fixed effects.

Table A7. **City-level pollution: Air quality**

This table examines the effects of the EPB reforms on air quality. The dependent variables are averaged city-year level air quality measures, sourced from CNRDS and available since 2014. AQI (column 1) is the Air Quality Index, a composite measure reflecting overall pollution levels; PM2.5 (column 2) represents fine particulate matter smaller than 2.5 microns (μg/m^3); PM10 (column 3) captures particulate matter smaller than 10 microns (μg/m^3). Columns 4–7 examine different degrees of pollution days within a city-year: slight pollution (column 4), moderate pollution (column 5), heavy pollution (column 6), and severe pollution (column 7). All regressions include city-level controls (as in column 2 of Table 2) and city and year fixed effects. Standard errors are clustered at the city level and reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

	Different Air Pollutants			Different Degrees of Pollution Days			
	AQI 1	PM2.5 2	PM10 3	Slight 4	Medium 5	Heavy 6	Severe 7
Post reform	-1.907**	-1.914***	-2.604**	-3.473	-4.354***	-2.021**	-0.746**
	(0.762)	(0.692)	(1.046)	(2.114)	(1.487)	(0.891)	(0.330)
City controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.939	0.922	0.936	0.920	0.859	0.796	0.709
Observations	1,404	1,404	1,404	1,404	1,404	1,404	1,404
Mean of dep. var.	75.68	46.12	81.00	67.28	21.90	8.80	1.61

Table A8. **City-level pollution: Pollutants**

This table examines the effects of the EPB reforms on different pollutants. The dependent variables are city-year level air and water pollutants, sourced from the Chinese City-Yearbook, available since 2003, except for NO_x, which is available from 2017 onward. Wastewater (column 1) refers to the volume of polluted water discharged by industrial and municipal sources (measured in million cubic meters); SO_2 (column 2) represents sulfur dioxide emissions, a major contributor to acid rain and respiratory issues (measured in thousand tons); Soot (column 3) refers to particulate emissions from combustion processes, such as industrial and vehicle emissions, which impact air quality and health (measured in thousand tons); and NO_x (column 4) represents nitrogen oxides, pollutants from combustion that contribute to smog and acid rain (measured in thousand tons). Panel A reports results for the full sample with data available from 2003, while Panel B restricts the sample period to 2014–2019, as the majority of cities underwent reform after 2014. All regressions include city-level controls (as in column 2 of Table 2) and city and year fixed effects. Standard errors are clustered at the city level and reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Full sample: 2003 (2017) - 2019

	Wastewater	SO_2	Soot	NO_x
	1	2	3	4
Post reform	-8.093	-6.398	-3.330	-0.169
	(5.936)	(5.865)	(2.672)	(0.639)
City controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.825	0.805	0.609	0.959
Observations	4,205	4,207	4,199	581
Mean of dep. var.	70.61	52.13	26.95	17.64

Panel B. Majority of reform period: 2014 - 2019

	Wastewater	SO_2	Soot
	1	2	3
Post reform	-6.145**	-7.953**	-12.572***
	(2.707)	(3.093)	(4.394)
City controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
R-squared	0.933	0.810	0.820
Observations	1,388	1,394	1,389
Mean of dep. var.	53.49	30.62	26.17

Table A9. **City-level output: GDP**

This table examines the effects of the EPB reforms on city-level output, as measured by the logarithm of GDP and GDP growth rate. All regressions include city-level controls (as in column 2 of Table 2, except for GDP) and city and year fixed effects. Standard errors are clustered at the city level and reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

	log(GDP)	log(GDP) (deflated)	GDP growth rate	GDP growth rate (deflated)
	1	2	3	4
Post reform	0.014	0.014	-2.430	-2.364
	(0.028)	(0.028)	(1.678)	(1.636)
City controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.982	0.980	0.121	0.110
Observations	4,360	4,360	4,088	4,088
Mean of dep. var.	24.40	24.17	15.17	12.13

Appendix A.4 Neighboring cities' reforms

We next investigate whether biodiversity in a city is influenced by reforms in neighboring cities. This investigation helps isolate the impact of such reforms while accounting for potential spatial spillover effects and redistribution effects (as discussed in Section 3.3).

In Table A10, we include both the indicator for the focal city's reform (*Post reform*) and that for neighboring cities' reforms (*Post neighbor reform*) in the baseline specification. The coefficient of *Post reform* remains positive and significant across all columns, consistent with the baseline results in Table 2. In contrast, the coefficient of *Post neighbor reform* shows mixed results: it is insignificant for bird species, and inconsistently significant across columns for bird abundance. Overall, our analysis suggests that reforms in adjacent cities did not exert a strong or statistically significant effect on focal biodiversity.

To further examine spillover effects, we estimate the effects of neighboring cities' EPB reforms on focal air quality and pollution outcomes. As reported in Tables A11 and A12, neighboring reforms appear to partially improve focal air quality but show no significant effects on other pollutant types.

These findings admit two interpretations. First, they may indicate that the effectiveness of environmental policy reforms is geographically contained, thereby reinforcing our causal inference. Alternatively, neighboring reforms could simultaneously generate spillover effects (improving the focal ecosystem) and redistribution effects (attracting birds from the focal city to neighboring cities), with these opposing forces canceling each other out.

Arguably, the absence of significant effects from neighboring reforms more likely reflects geographically contained policy impacts rather than offsetting forces. Environmental quality improvements from neighboring reforms are only partial, suggesting limited cross-border spillover capacity, which would similarly constrain both ecological benefits and bird redistribution effects. Moreover, redistribution effects need not be constrained by a fixed total bird population—bird species from focal cities could establish populations in neighboring cities after they are reformed without reducing the focal city's bird population. While distinguishing between these interpretations remains challenging, doing so lies beyond the scope of this paper.

Table A10. **Neighbor cities' reforms and bird diversity**

This table examines the spillover effects of neighboring cities' EPB reforms on focal bird diversity. The model specifications are identical to those in Table 2, with the addition of a dummy variable indicating whether any neighboring city has implemented an EPB reform. All regressions include city and year fixed effects. Standard errors clustered at the city level are reported in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	Bird species (city-year level)		Bird observation rate (event level)		
	1	2	3	4	5
Post reform	19.347***		25.183**	25.926***	
	(7.379)		(10.468)	(9.814)	
Post neighbour reform	-0.901	3.677	21.592**	2.416	1.132
	(6.644)	(6.207)	(10.104)	(8.891)	(8.650)
Controls	Yes	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes	Yes
Birdwatching account FE				Yes	Yes
R-squared	0.776	0.774	0.153	0.257	0.257
Observations	1,422	1,422	41,074	40,267	40,267

Table A11. **Neighbor cities' reforms and air quality**

This table examines the effects of both focal and neighboring cities' EPB reforms on air quality. The model specifications are identical to those in Table A7, with the addition of a dummy variable indicating whether any neighboring city has implemented an EPB reform. Standard errors are clustered at the city level and reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

	Different Air Pollutants			Different Degrees of Pollution Days			
	AQI 1	PM2.5 2	PM10 3	Slight 4	Medium 5	Heavy 6	Severe 7
Post reform	-1.755**	-1.802***	-2.049*	-3.242	-3.529**	-1.587*	-0.615*
	(0.765)	(0.687)	(1.042)	(2.120)	(1.454)	(0.853)	(0.313)
Post neighbor reform	-0.551	-0.410	-2.018**	-0.840	-3.003***	-1.580***	-0.479**
	(0.660)	(0.582)	(0.896)	(1.759)	(1.138)	(0.592)	(0.206)
City controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clustered by city	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.939	0.922	0.936	0.920	0.860	0.797	0.710
Observations	1,404	1,404	1,404	1,404	1,404	1,404	1,404
Mean of dep. var.	75.68	46.12	81.00	67.28	21.90	8.80	1.61

Table A12. **Neighbor cities' reforms and pollutants**

This table examines the effects of both focal and neighboring cities' EPB reforms on pollutatns. The model specifications are identical to those in Table A8, with the addition of a dummy variable indicating whether any neighboring city has implemented an EPB reform. Standard errors are clustered at the city level and reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Full sample: 2003 (2017) - 2019

	Wastewater	SO_2	Soot	NO_x
	(1)	(2)	(3)	(4)
Post reform	-5.485	-8.328	-3.449	-0.207
	(5.671)	(6.158)	(2.802)	(0.627)
Post neighbor reform	-6.832	5.030	0.312	0.165
	(4.473)	(3.350)	(2.231)	(0.518)
City controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.825	0.806	0.609	0.959
Observations	4,205	4,207	4,199	581
Mean of dep. var.	70.61	52.13	26.95	17.64

Panel B. Majority of reform period: 2014 - 2019

	Wastewater	SO_2	Soot
	(1)	(2)	(3)
Post reform	-5.736*	-7.737**	-11.981***
	(2.970)	(3.712)	(4.164)
Post neighbor reform	-1.320	-0.695	-1.911
	(2.124)	(3.382)	(2.811)
City controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
R-squared	0.933	0.810	0.821
Observations	1,388	1,394	1,389
Mean of dep. var.	53.49	30.62	26.17

Appendix A.5 Pollution types and bird diversity

The granularity of the environmental penalty data enables a deeper understanding of how different types of pollutants affect biodiversity. The Environmental Protection Administrative Penalties dataset provides detailed reasons for each penalty issued, with most cases falling into four pollution categories: air, water, solid waste, and industrial noise. Following the approach in Panel B of Table 4, we categorize cities into stricter and looser enforcement groups based on penalty increases within each pollutant category and examine the effects of the reform on bird diversity.

The results, presented in Table A13, indicate that in addition to air pollution[34], solid waste plays a critical role in biodiversity outcomes. These findings underscore the importance of considering a broader range of pollutants when researching biodiversity and sustainable finance-related topics. Each type of pollution carries significant environmental consequences, and policymakers, firms, and investors should account for the impact of multiple pollutants beyond air and water when assessing environmental risks and sustainability practices.

[34] Existing research has primarily focused on air and water pollution (e.g., Greenstone and Hanna, 2014; Dasgupta et al., 2023)

Table A13. **Pollution types and bird diversity**

This table presents the results of an analysis examining the impacts of penalties associated with four types of pollution—air, water, solid waste, and industrial noise—on local bird species (panel A) and abundance (panel B). Cities are categorized into "stricter" (above median) and "looser" (below median) subsamples based on the total number of penalties imposed for these pollution types. The "strictness in enforcement" or "increase in penalties" is calculated as the difference in the number of penalties between the reform year 0 and the year -2. The dependent variable in Panel A is bird species, and the dependent variable in Panel B is bird observation rate. Control variables are identical to columns 3 and 6 of Table 2. The *Diff p-values* refer to the p-value of the SUEST test, which compares the coefficients across different models. Standard errors are clustered at the city level and are reported in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

Panel A. Bird species (city-year level)

	Air pollution		Water pollution		Solid waste		Industrial noise	
	Stricter	Looser	Stricter	Looser	Stricter	Looser	Stricter	Looser
	Diff p-value: 0.028		*Diff p-value: 0.251*		*Diff p-value: 0.021*		*Diff p-value: 0.544*	
Post reform	28.765***	5.179	15.838*	0.919	29.195***	-0.279	24.365**	8.752
	(9.915)	(8.366)	(9.513)	(8.209)	(10.300)	(8.092)	(10.969)	(12.067)
City and birdwatching controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.796	0.826	0.786	0.847	0.791	0.828	0.824	0.829
Observations	707	671	694	573	744	640	557	420

Panel B. Bird observation rate (event level)

	Air pollution		Water pollution		Solid waste		Industrial noise	
	Stricter	Looser	Stricter	Looser	Stricter	Looser	Stricter	Looser
	Diff p-value: 0.106		*Diff p-value: 0.123*		*Diff p-value: 0.047*		*Diff p-value: 0.788*	
Post reform Post reform	34.985**	11.056	36.852**	-4.116	38.539**	4.205	22.259*	32.262
	(15.492)	(14.503)	(16.457)	(14.303)	(16.666)	(11.029)	(13.248)	(26.519)
City and birdwatching controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.140	0.185	0.142	0.196	0.141	0.214	0.163	0.115
Observations	25,693	14,674	24,539	13,129	26,244	14,198	24,366	10,697

Appendix B Figures and tables

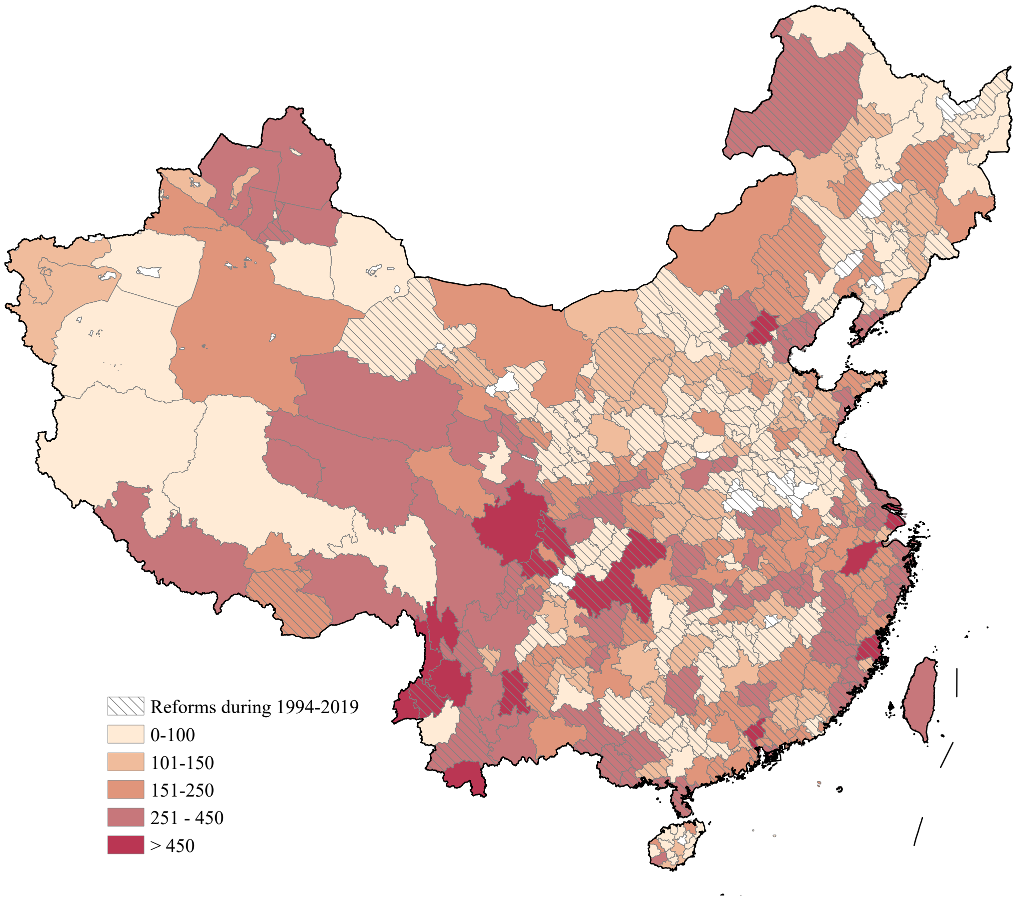
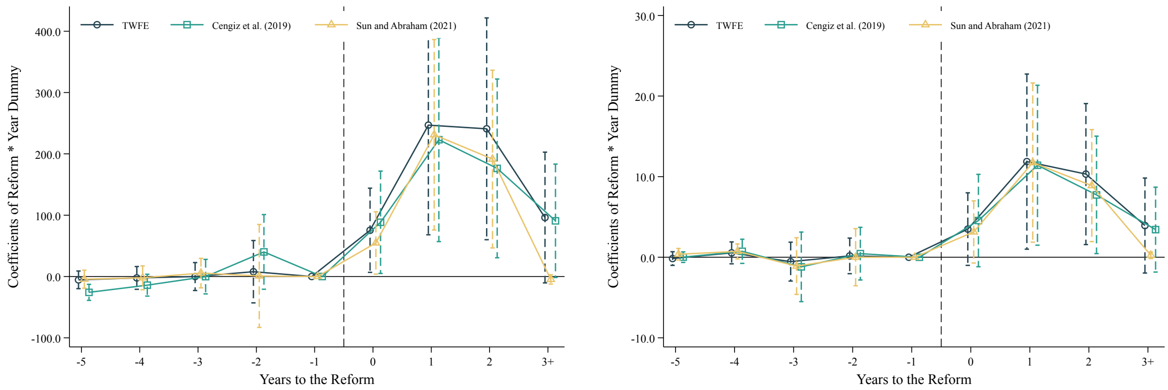
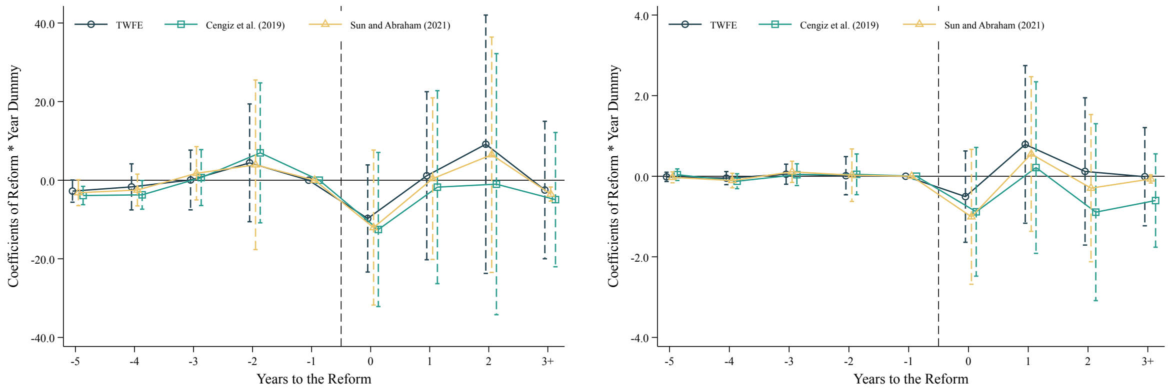


Figure B1. **Number of bird species and reformed cities, 2003–2019.**

Notes: This figure illustrates the spatial distribution of bird species richness across Chinese cities based on the total number of unique bird species observed from 2003 to 2019. The data is derived from birdwatching records sourced from *eBird.com* and *birdreport.cn*. During the sample period, a total of 1,750 bird species were recorded across China. Shaded cities are those that implemented an EPB reform during the period 2003–2019.



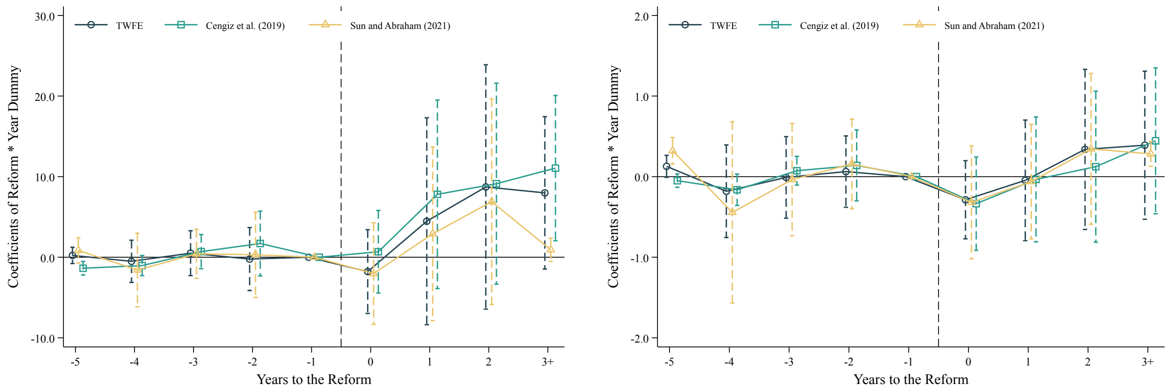
(a) Panel A. Local firms: number of penalties and fine amount



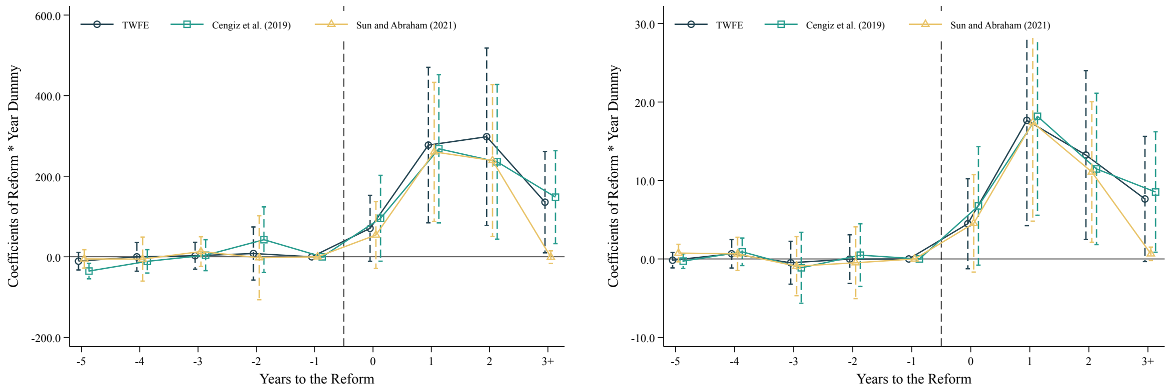
(b) Panel B. Non-local firms: number of penalties and fine amount

Figure B2. **The effects of EPB reforms on penalties: Local vs. Non-local firms.**

Note: This figure shows the pre- and post-trends in the effect of EPB reforms on penalties while dividing the sample into local (Panel A) and non-local (Panel B) firms. The coefficients (with 95% confidence intervals) are obtained from regressing the number of penalties and the total fine amount (in million yuan) on relative-to-reform year dummies for the period between 2003 and 2019. We report estimates from a two-way fixed effects (TWFE) model, the stacked DiD approach (Cengiz et al., 2019), and the Sun and Abraham (2021) method. The year immediately preceding reform (year −1) serves as the reference period. "Year −5" denotes five years prior to reform, and "year 3" denotes three or more years post-reform. All regressions control for city-level and birdwatching event characteristics (see Table 2), as well as city and year fixed effects.



(a) Panel A. SOEs: number of penalties and fine amount



(b) Panel B. POEs: number of penalties and fine amount

Figure B3. **The effects of EPB reforms on penalties: SOE vs. POE.**

Note: This figure shows the pre- and post-trends in the effect of EPB reforms on penalties while dividing the sample into SOEs (Panel A) and POEs (Panel B). The coefficients (with 95% confidence intervals) are obtained from regressing the number of penalties and the total fine amount (in million yuan) on relative-to-reform year dummies for the period between 2003 and 2019. We report estimates from a two-way fixed effects (TWFE) model, the stacked DiD approach (Cengiz et al., 2019), and the Sun and Abraham (2021) method. The year immediately preceding reform (year −1) serves as the reference period. "Year −5" denotes five years prior to reform, and "year 3" denotes three or more years post-reform. All regressions control for city-level and birdwatching event characteristics (see Table 2), as well as city and year fixed effects.

Table B1. **Bird observation rate by effort hours**

This table presents the summary statistics of bird observation rate, i.e. the number of birds observed per hour in each birdwatching event, conditional on the event duration, i.e. effort hours of each birdwatching event.

		Bird observation rate			
Event duration (in hours)	# events	Mean	S.D.	Min	Max
0–0.25	1,505	790.00	6,263.22	4.29	199,320.00
0.25–0.5	2,253	212.12	1,182.23	2.11	23,462.50
0.5–1	6,242	122.39	548.99	1.02	22,897.89
1–4	30,467	91.80	460.81	0.25	32,356.77
4–8	13,514	71.73	368.85	0.13	22,268.20
8–12	5,357	59.95	284.43	0.08	11,294.13
12–16	941	32.72	144.29	0.07	3,017.08
16–24	1,083	22.12	114.53	0.04	3,312.07
$\geq$24	4,020	8.85	49.71	0.00	1,509.17

Table B2. Variable definitions

Variable	**Definition**
Independent variables, 2003–2019	
Post Reform (dummy)	Equals 1 for cities that have implemented EPB reform by year t.
Birdwatching (city–year), 2003–2019	
Bird species	Number of unique bird species observed.
Total # birdwatching events	Number of birdwatching events in a city-year.
Total effort hours	Sum of event durations (in hours, end time minus start time) of all birdwatching events in a city-year.
Birdwatching (event level), 2003–2019	
Bird observation rate	Number of birds observed per hour in an event.
Effort hours per event	Event duration (in hours, end time minus start time).
City–year controls, 2003–2019	
Population density (1,000 persons/sq.km)	Population (1,000 persons) divided by land area (sq.km).
Urbanization rate (%)	Share of population in urban areas.
GDP (billion yuan)	Gross Domestic Product.
Primary industry (% of GDP)	Primary industry output / GDP.
Secondary industry (% of GDP)	Secondary industry output / GDP.
Real estate investment (% of GDP)	Investment in real estate / GDP.
Green space ratio (%)	Green space area / total land area.
Temperature (°C)	Annual average temperature (monthly data aggregated).
Precipitation (mm)	Annual average precipitation (monthly data aggregated).
Wind speed (m/s)	Annual average wind speed (from lat/long components; monthly data aggregated).
Number of disasters	Total number of natural and technological disasters within a city-year.
Enforcement (city–year), 2003–2019	
Number of penalties	Count of administrative environmental penalties.
Fine amount (million yuan)	Total fines from environmental penalties.
Fine amount (million yuan, 2003=100)	Total fines deflated to 2003 prices.
Firm-level variables, 2003–2019	
Is penalized	Equals 1 if the parent entity of the firm was penalized on day t (for firm-day analyses) or in year t (for firm-year analyses).
Is penalized (incl. subsidiaries)	Equals 1 if the parent entity or any subsidiary of the firm was penalized on day t (for firm-day analyses) or in year t (for firm-year analyses).
Is penalized, industry peer (incl. sub.)	Equals 1 if any other firm (parent or subsidiaries) in the same industry (as defined by GB/T 4754—2017 industry classification) was penalized in year t.
Is penalized, city peer (incl. sub.)	Equals 1 if any other firm (parent or subsidiaries) located in the same city as penalized in year t.
News sentiment	The average news-sentiment score across all news articles focusing on the firm on day t.
CAR [-1, 3] or [-1, 5]	The cumulative abnormal return over the [-1, 3] or [-1, 5] penalty event window. The benchmark is CAPM model where the market return is measured by the SSE Composite Index return. The estimation window is [-210,-10] trading days. The sample includes publicly traded firms that were penalized at least once during 2003–2019.

Variable definitions (cont')

Variable	**Definition**
Debt cost (%)	The ratio of (Net) Financial Expenses to the sum of Total Non-current Liabilities, Short-term Borrowings, and Current Portion of Non-current Liabilities in each firm-year. Net financial expenses include interest expenses (net of interest income), exchange losses (net of exchange gains), and related fees.
Tobin's Q (%)	The ratio of the market value to the book value in each firm-year.
Institutional ownership (%)	The proportion of tradable A-shares held by institutional investors in each firm-year, including mutual funds, securities firms, insurance companies, social security funds, and Qualified Foreign Institutional Investors (QFII)
Sales growth (%)	The percentage change in a firm's sales revenue relative to the previous year in each firm-year.
Standardized emissions	The average of the z-score of multiple firm-level emission indicators (COD, NH_3–N, total nitrogen, total phosphorus, SO_2, NO_x, and soot) for each firm-year.
COD (tons)	Chemical oxygen demand.
NH_3-N (tons)	Ammoniacal nitrogen emissions.
SO_2 (tons)	Sulfur dioxide emissions.
NO_x (tons)	Nitrogen oxides emissions.
Number of green patents applied	The number of green patent applications filed by a firm within a year.
Firm size	The natural logarithm of total assets in each firm-year.
Leverage	The ratio of total debt to total assets in each firm-year.
ROA	The ratio of net income to the average total assets, where average total assets equal the mean of beginning and ending total assets within a fiscal year.
Firm age	The number of years since the firm's establishment, calculated as the current year minus the establishment year plus one.
Green patents (city–year), 2003–2019	
Number of green patents applied	The total number of green patent applications filed by all firms within a city-year
Number of green patents applied, POE	Green patent applications by privately owned enterprises.
Number of green patents applied, SOE	Green patent applications by state-owned enterprises.
Pollution (city–year)	
Air quality, 2014–2019	
AQI	Air Quality Index (0–500; higher is worse).
PM2.5 (μg/m^3)	Fine particles $\leq 2.5\mu$m.
PM10 (μg/m^3)	Particles $\leq 10\mu$m.
Slight pollution days	Days with AQI in "Moderate" (101–150).
Moderate pollution days	Days "Unhealthy for Sensitive Groups" (151–200).
Heavy pollution days	Days "Unhealthy" (201–300).
Severe pollution days	Days "Very Unhealthy/Hazardous" ($\geq$301).
Pollutants, 2003–2019	
Wastewater (million tons)	Volume of discharged wastewater.
SO_2 (1,000 tons)	Sulfur dioxide emissions.
Soot (1,000 tons)	Particulate (soot) emissions.
NO_x (1,000 tons)	Nitrogen oxides emissions.

Table B3. **Baseline with standardized (z score) of dependent variables**

This table replicates column 3, 6 and 7 of Table 2 except that the dependent variables are standardized (z score). Standard errors clustered at the city level are reported in parentheses. Standard errors adjusted for arbitrary clustering to account for spatial correlation are reported in brackets (Colella et al., 2019). *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

	z of Bird species (city-year)	z of Bird observation rate (event level)	
	1	2	3
Post reform	0.242	0.116	0.121
	(0.086)***	(0.053)**	(0.045)***
	[0.094]***	[0.055]**	[0.045]***
City and birdwatching controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
Birdwatching account FE			Yes
R-squared	0.776	0.152	0.257
Observations	1,422	41,074	40,267

Table B4. **Effect of EPB Reforms on Environmental Penalties (z score)**

This table replicates Panel A of Table 4, except that the dependent variables are standardized (z-score). All regressions include city and year fixed effects. The analysis encompasses 277 cities from 2003 to 2019 in China. Standard errors clustered at the city level are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	z of # penalties	z of total fine	z of total fine (deflated)
	1	2	3
Post reform	0.397**	0.405**	0.404**
	(0.170)	(0.198)	(0.197)
City controls	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes
R-squared	0.430	0.418	0.419
Observations	4,360	4,360	4,360

Table B5. **EPB reform effects by enforcement intensity (stricter vs. looser), alternative years**

This table replicates Panel B of Table 4, but varies the years used to classify cities into "stricter" and "looser" enforcement groups. In Panel A, cities are categorized based on the change in enforcement intensity between the reform year (0) and one year before the reform (-1). In Panel B, cities are categorized using the change in enforcement between year 1 and year -1 relative to the reform. Standard errors are clustered at the city level and are reported in parentheses. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Panel A. Year (0) - year (-1)

	Bird species		Bird observation rate	
	Stricter	Looser	Stricter	Looser
	1	2	3	4
Post reform	24.936***	14.791	63.330***	3.728
	(9.376)	(9.339)	(23.839)	(6.459)
City controls	Yes	Yes	Yes	Yes
Birdwatching controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.775	0.809	0.168	0.106
Observations	648	660	16,987	21,226

Panel B. Year (1) - year (-1)

	Bird species		Bird observation rate	
	Stricter	Looser	Stricter	Looser
	1	2	3	4
Post reform	21.784**	19.069	48.694**	-0.365
	(9.064)	(12.833)	(21.050)	(4.369)
City controls	Yes	Yes	Yes	Yes
Birdwatching controls	Yes	Yes	Yes	Yes
City and Year FE	Yes	Yes	Yes	Yes
R-squared	0.776	0.801	0.156	0.104
Observations	650	642	18,452	19,261

Table B6. **Penalties towards foreign firms**

This table examines the effects of the EPB reforms on environmental penalties imposed on foreign firms, as identified by *tianyancha.com*. The regressions replicate columns 2 and 4 of Panel A of Table 4, except that the dependent variable is the number or total amount of penalties directed at foreign firms. Standard errors are clustered at the city level and are reported in parentheses. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

	Foreign firms	
	Number of penalties	Total fine amount
	1	2
Post reform	7.516*	1.347**
	(4.178)	(0.568)
City controls	Yes	Yes
City and Year FE	Yes	Yes
R-squared	0.414	0.282
Observations	4,360	4,360

Table B7. **Penalties and individual pollutants**

This table examines the effects of penalties and the EPB reform on firm-level emissions. We consider four major pollutants commonly disclosed in corporate environmental reports: COD (tons) i.e., Chemical Oxygen Demand; NH_3–N (tons) i.e., Ammoniacal nitrogen emissions; SO_2 (tons) i.e., Sulfur dioxide emissions; and NO_x (tons) i.e., Nitrogen oxides emissions. Panel A and B replicate column 1 and 4 of Panel A in Table 6, respectively, except that the dependent variable is replaced by each of the four pollutant measures listed above. All regressions include firm and city-level controls, and firm and year fixed effects. Standard errors clustered at the city level are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Effects of Environmental penalties on pollutants

	COD	NH_3–N	SO_2	NO_x
	1	2	3	4
Is penalized (incl. subsidiaries)	-5.673**	-3.993**	-3.719**	-4.455*
	(2.857)	(1.741)	(1.719)	(2.398)
Firm controls	Yes	Yes	Yes	Yes
City controls	Yes	Yes	Yes	Yes
Firm and Year FE	Yes	Yes	Yes	Yes
R-squared	0.249	0.810	0.844	0.869
Observations	77,800	77,754	77,757	77,654

Panel B. Effects of EPB reform on pollutants

	COD	NH_3–N	SO_2	NO_x
	1	2	3	4
Post reform	-17.955**	-8.904*	-10.876**	-12.808*
	(8.676)	(5.282)	(5.137)	(6.870)
Firm controls	Yes	Yes	Yes	Yes
City controls	Yes	Yes	Yes	Yes
Firm and Year FE	Yes	Yes	Yes	Yes
R-squared	0.273	0.810	0.847	0.869
Observations	25,834	25,860	25,826	25,826

References (Appendix)

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