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The Roles of Beijing-Tianjin-Hebei Coordinated Development Strategy in Industrial Energy and Related Pollutant Emission Intensities

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Abstract: This study investigates the different impacts of coordinated development in the Beijing–Tianjin–Hebei (BTH) region on industrial energy and pollution intensities based on the difference-in-difference (DID) method and the quantile DID method. The panel data cover industrial energy consumption and three wastes, which are industrial wastewater, sulfur dioxide, and dust emissions, from all 13 cities in the BTH region and 17 cities in Henan Province for the period 2007–2017. The study finds that China's BTH coordinated development strategy, on average, tends to restrain regional industrial energy intensity, especially in lower quantile level (0.1–0.4) cities. However, it tends to promote industrial energy intensity in higher quantile level (0.7–0.9) cities. The impacts on pollution intensities vary among industrial wastewater, sulfur dioxide, and dust emissions. The results suggest that, in addition to paying attention to dust pollution caused by transportation integration in the BTH region, China should also pay more attention to green relocation of industries from Beijing to Hebei and strengthen coordinated environmental regulation while maintaining corporate interests.

Keywords: industrial energy intensity; pollution emission intensity; quantile DID method; Beijing–Tianjin–Hebei coordinated development; China

1. Introduction

Industrial pollution is one of the world's most serious environmental problems. In China, industries are the largest source of pollution, especially for air contamination. Any form of pollution that can be directly traced back to industrial practice is called industrial pollution. Most of the pollution on Earth can be traced back to some kind of industry [1]. Therefore, the reduction of industrial pollution has always been critical in dealing with environmental degradation around the world. Most developing countries facing the rapid growth of industrial pollution found it to be a serious problem that must be brought under control. However, major environmental disasters caused by industrial accidents still occur sometimes in developing countries.

As for China, environmental pollution mainly comes from traditional heavy industries, especially power plants, petrochemical industries, metal smelting, and machinery manufacturing, which produce a large volume of sulfur dioxide, dust, and wastewater. In the face of unprecedented economic and industrial growth levels, China rapidly developed its system of environmental governance [2,3]. It can be used to reform the highly inefficient and strictly regulated energy market [4] and to improve the regulation of industrial pollution [5]. The reasons may be the two-level pressures including domestic economic growth and international governance status [6]. In recent years, China's governing system resulted in a lot of environmental policy implementations from the central government [7], which have had a noticeable effect on improving the environment [8]. Although great achievements in some fields like solar photo voltaic, wind energy, and nuclear power have been made [9], China still faces many energy-related challenges including air pollution, urbanization, and climate change in the future [10].

The Beijing–Tianjin–Hebei (BTH) region is China's "capital economic circle", including Beijing, Tianjin, and 11 prefecture-level cities of Hebei province. It is one of the three major urban agglomerations and has the strongest industrial base in China, accounting for about 2% of the national land area, 10% of the national GDP, and 8% of the total population. However, there is a huge economic disparity in this region. In terms of per capita GDP in 2019, the per capita GDPs of Beijing, Tianjin, and Hebei were USD 23,600, USD 13,100, and USD 6,800, respectively. In terms of the industrial structure in 2019, Beijing's tertiary industry accounted for 83% and the secondary industry accounted for only 16%, while Tianjin and Hebei's secondary industries accounted for 36% and 41%, respectively. In terms of urbanization rate in 2019, the urbanization rates of Beijing, Tianjin, and Hebei were 86%, 83%, and 56% respectively.

The BTH region in which environmental degradation is prominent in China has been dominated by some energy-intensive industries like mining and steelmaking sectors, especially in Hebei province. The common problem of the three areas is the consumption of fossil energy and the three wastes it brings, including industrial wastewater, sulfur dioxide, and dust emissions, which are the main causes of environmental problems in this region. The three wastes are related to fossil energy because sulfur dioxide and dust emission are mainly produced by fossil energy consumption, while industrial wastewater, although not entirely produced by fossil energy, is overall strongly correlated with energy consumption.

In February 2014, Chinese President Xi Jinping proposed the coordinated development strategy of the BTH region, which is a national strategy in China. The strategy is to build a new capital economic circle and to promote innovation of regional development. First, it is to explore a mode of optimal development of this densely populated and economically intensive area. Second, it will take the lead in making breakthroughs in three key areas: ecological and environmental regulation, industrial upgrading and transfer, and the integration of the BTH transport sector. It is expected to ease the increasing pressure on resources and environment, to accelerate the transformation of economic development patterns, and to promote balanced development for the BTH region.

The Outline of the Coordinated Development Plan in the BTH region approved by the Chinese government in 2015 made a clear definition of the core functions of Beijing: the national political center, the cultural center, the international communication center, and the scientific and technological innovation center. The industries that do not accord with these certain orientations should be gradually relocated to Tianjin and Hebei province. Tianjin is identified as an important city but subordinate to the core city of Beijing, and thus, it is meant to take on complementary functions [11]. By 2019, nearly 10,000 enterprises had been relocated out of Beijing, most of which were high-end manufacturing and high-tech service industries. These industries may not fit Beijing's new orientation, but for Tianjin and Hebei, they can promote local industrial upgrade through the relocation. It is worth mentioning that the "transfer" is not transferring polluting industries. During the transfer process, enterprises should upgrade or switch to sustainable and environmentally friendly businesses. If they do not want to relocate, they can upgrade locally following the new and more stringent environmental protection standards. Therefore, the feature of this strategy is that it seeks to address environmental and social issues in the process of coordinated development while also laying the foundation for sustainable development through environmental constraints.

In recent years, some major projects involving the coordinated development of the BTH region have been launched. For example, Beijing and Hebei will jointly organize the 2022 Beijing Winter Olympics, Beijing and Tianjin are fully supporting the development of the Hebei Xiong'an New

Area, and the Chinese government has been supporting the orderly transfer and sharing of Beijing's scientific and technological innovation resources and high-quality public service resources in this region. More importantly, Beijing, Tianjin, and Hebei were together dedicated to deepening joint prevention and control of the increasing regional environmental degradation.

From the perspective of sustainable development, what impacts this strategy has had on fossil energy intensity and related pollution intensities in the BTH region are absent in the literature. To fill this gap, this paper is therefore intended to empirically study the roles of the BTH coordinated development strategy in industrial energy and pollution intensities based on the difference-in-difference (DID) method and the quantile DID method. The results of this study will help clarify the potential problems in the implementation of this strategy and provide some empirical evidence and policy implications for green and sustainable development in this region. The implementation of the BTH coordinated development strategy provides an effective quasi-natural experiment in assessing the impact of specific policy events on industrial energy intensity and related pollution intensities.

The study has made three contributions. First, it investigates the comprehensive impact of the BTH coordinate development strategy on industrial energy and pollution intensities, and the estimation results are robust based on a number of statistical tests. Second, this study applies the quantile DID method to evaluate the heterogeneous impact of the strategy on industrial energy intensity in the BTH region at different quantile levels of industrial energy intensity. Third, this study uses the data of industrial energy pollutions to estimate the different impacts of the strategy on the environment among different energy pollution sources. Such heterogeneous effects can help make policy implications based on different pollution sources under the context of the strategy.

There are three findings from this study. First, based on the DID method results, China's BTH coordinated development strategy, on average, tends to restrain regional industrial energy intensity in this region. Second, based on the quantile DID method results, the BTH coordinated development strategy tends to restrain the industrial energy intensity in lower quantile level cities but tends to increase the industrial energy intensity in higher quantile level cities. Third, the impacts of the BTH coordinated development strategy on the environment vary among three industrial energy-related pollution sources including wastewater, sulfur dioxide, and dust emissions.

In Section 2, we introduce the study areas and provide some basic statistics about this region. In Section 3, we conduct a literature review and analyze the mechanism between the BTH coordinated development strategy and industrial energy consumption. Section 4 estimates a regression model for industrial energy intensity based on the DID method. Section 5 assesses the impact of the BTH coordinated development strategy on industrial energy and pollution intensity empirically. Finally, Section 6 provides the conclusion, policy implications, and discussions.

2. The Study Areas

As shown in Figure 1, Beijing is located in the north of China and north of the BTH region. It borders Tianjin in the east and some cities of Hebei in the rest. It is the capital of the People's Republic of China, a municipality directly under China's central government, a national central city, and a megacity in the world. The total area of Beijing is 16,410 square kilometers, and it has 16 districts under its jurisdiction. By the end of 2019, there were 21.536 million permanent residents and 18.5 million urban residents, representing an urbanization rate of 86.6 percent. The GDP of Beijing in 2019 was RMB 3537.13 billion yuan, and the per capita GDP was RMB 164,000 yuan. The proportions of primary, secondary, and tertiary industries are 0.3%, 16.2%, and 83.5%, respectively. Besides, the energy consumption per unit of GDP in 2019 was about 0.25 tons of standard coal per RMB 10,000 yuan, which was the lowest in China.

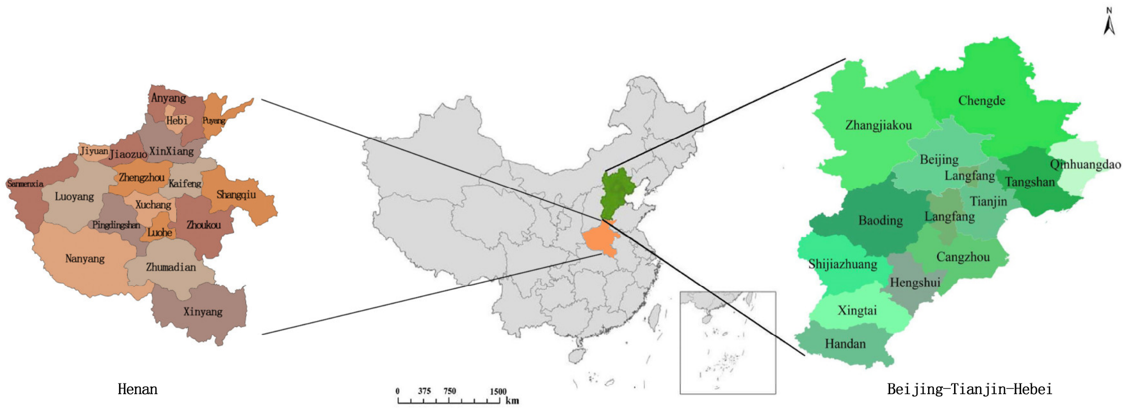

Figure 1. Locations of the Beijing–Tianjin–Hebei (BTH) region and Henan Province.

Tianjin, a municipality directly under the central government of China, is a national central city, a megacity, and the largest port city in north China. It borders Beijing in the west and some cities of Hebei in the rest. The total area of Tianjin is 11,966 square kilometers with 16 districts under its jurisdiction. By the end of 2019, there were 15.618 million permanent residents and 13.038 million urban residents, representing an urbanization rate of 83.5 percent. The GDP of Tianjin in 2019 was RMB 1410.43 billion yuan, and the per capita GDP was RMB 90,000 yuan. The proportions of primary, secondary, and tertiary industries were 1.3%, 35.2%, and 63.5%, respectively. Besides, the energy consumption per unit of GDP in 2019 was about 0.41 tons of standard coal per RMB 10,000 yuan. Now, the ecological civilization has also become an important element for the urban development of Tianjin under the coordinated development strategy of the BTH region [11].

Hebei province is located in the north of China, bordering the Bohai Sea in the east and Beijing and Tianjin in the inner ring. The total area of Hebei province is 188,800 km^2, and it has 11 prefecture-level cities under its jurisdiction, including Shijiazhuang, Tangshan, Qinhuangdao, Baoding, Handan, Xingtai, Zhangjiakou, Chengde, Cangzhou, Hengshui, and Langfang, with Shijiazhuang as its provincial capital. By the end of 2019, there were 75.920 million permanent residents and the permanent resident urbanization rate was 57.6 percent. The GDP of Hebei in 2019 was RMB 3510.45 billion yuan, and the per capita GDP was RMB 46,000 yuan. The proportions of primary, secondary, and tertiary industries were 10.3%, 39.7%, and 50.0%, respectively. Besides, the energy consumption per unit of GDP in 2019 was about 0.84 tons of standard coal per RMB 10,000 yuan, which was much higher than the national average of 0.51 tons of standard coal equivalent per RMB 10,000 yuan. Hebei province is rich in mineral resources because 156 kinds of mineral resources have been discovered, 39 of which are among the top 5 in China. It has formed a mining economic system with metallurgy, coal, building materials, and petrochemicals. In April 2017, the central government decided to establish Xiong'an New Area in Hebei province. In August 2019, the state council established a new China (Hebei) Pilot Free Trade Zone.

The control group, Henan Province, is located in central China, south of Hebei province, with a total area of 167,000 km^2. It has jurisdiction over 17 prefecture-level cities, including Zhengzhou, Kaifeng, Luoyang, Pingdingshan, Anyang, Hebi, Xinxiang, Jiaozuo, Puyang, Xuchang, Luohe, Sanmenxia, Shangqiu, Zhoukou, Zhumadian, Nanyang, and Xinyang, with Zhengzhou as the provincial capital and Jiyuan as a county-level city directly under the jurisdiction of Henan Province. By the end of 2019, there were 109.52 million permanent residents and the permanent resident urbanization rate was 53.2 percent. The GDP of Henan in 2019 was RMB 5425.92 billion yuan, and the per capita GDP was RMB 56,000 yuan. The proportions of primary, secondary, and tertiary industries were 8.5%, 43.5%, and 48.0%, respectively. Energy consumption per unit of GDP in 2019 was about 0.48 tons of standard coal per RMB 10,000 yuan. Henan province is also rich in mineral resources because 142 kinds of mineral resources have been discovered, 58 of which are among the top 5 in China.

In general, Beijing is dominated by the service industry, Tianjin is dominated by the processing and manufacturing industry and by the port service industry, and Hebei is dominated by the resource-intensive industry and agriculture because of the rich mineral resources and rural labor force. Therefore, we can also conclude the following socioeconomic characteristics in the BTH region. First, the issues of industrial pollution are very serious. The heavy industries in Hebei and Tianjin lead to great pressure on the environment, especially serious air pollution. Second, economic development is very unbalanced. Hebei is geographically advantaged with three port cities including Tangshan, Cangzhou, and Qinhuangdao, and most of the cities are very close to Beijing and Tianjin. However, there is a huge gap in economic development as the above statistics show. Third, as the capital city, Beijing has strong political, economic, cultural, scientific, and technological strength. However, there has always been a "siphon effect" of talents, funds, and other resources transferring from Hebei and even Tianjin to Beijing. Therefore, Beijing has a very weak radiation effect on the surrounding cities. Fourth, under the BTH coordinated development strategy, Tianjin has changed to a more sustainable urban development model. For example, the Sino-Singaporean Eco-city replaced Hanggu to become one subcenter of the Binhai New Area of Tianjin, as it is a national project that retains a high level of support from the central government for environment protection in the BTH region.

Based on the outline of the coordinated development plan, Beijing is the national center for political, cultural, and international exchanges and for scientific and technological innovation; Tianjin is the national advanced manufacturing research and development base, the northern international shipping core zone, and the financial innovation operation and reform pilot demonstration zone, and Hebei is an important base for modern trade and logistics in China, a pilot area for industrial transformation and upgrading, a demonstration area for new urbanization and urban-rural integration, and a supporting area for the BTH ecological environment. The overall orientation of the BTH region is "a world-class city cluster with the capital as the core, a leading area for coordinated regional development and reform, a new national engine for innovation-driven economic growth, and a demonstration area for ecological restoration and environmental improvement". The overall development plan can be concluded as "one core, two cities, three axes, four areas, and multiple nodes". "One core" means Beijing, and "two cities" refer to Beijing and Tianjin. They are the main engines for the coordinated development of the BTH region so the linkage between Beijing and Tianjin needs to be further strengthened. "Three axes" refer to the three industrial development and urban agglomeration axes, including Beijing–Tianjin, Beijing–Baoding–Shijiazhuang, and Beijing–Tangshan–Qinhuangdao. "Four areas" refer to the central core functional area, the eastern coastal development area, the southern functional extension area, and the northwest ecological conservation area. "Multiple nodes" include regional central cities such as Shijiazhuang, Tangshan, Baoding, and Handan and node cities such as Zhangjiakou, Chengde, Langfang, Qinhuangdao, Cangzhou, Xingtai, and Hengshui, with the focus on improving these cities' comprehensive carrying capacity and service capacity and on promoting industry and population aggregation in an orderly manner.

There are some reasons why the Chinese government made great effort to develop this region. First, the coordinated development of this region is conducive to solving Beijing's "big-city diseases" such as population expansion, traffic congestion, housing difficulties, environmental degradation, and resource shortage. Second, the BTH region lags behind China's Yangtze River Delta and Pearl River Delta but it has a huge development potential. Third, the economic capabilities are extremely uneven among cities. Beijing and Tianjin lead the country in urbanization rate and per capita GDP, while those of Hebei cities are below the national averages. For example, Beijing's pillar industries are finance, information technology, and science and technology research, but Tianjin and Hebei are dominated by medium- and low-end manufacturing industries with lots of pollution. The milestones are as follows. By 2017, remarkable progress was made in the orderly relocation of noncapital functions of Beijing and some breakthroughs occurred in key areas such as transportation integration, environmental protection, and industrial upgrading and relocation. By 2020, the population of Beijing should be controlled within 23 million, an integrated regional transport network will be shaped, the environment will effectively improved, major progress will be made in the coordinated development of industries, and the development gaps within the region should be narrowed. By 2030, the core functions of Beijing will be improved, the regional economic structure will become more reasonable, the environmental quality will improve, and the levels of public services should be balanced. In the end, the BTH region will become a region with strong international competitiveness and influence, thus playing a greater role in guiding and supporting China's economic and social sustainable development.

3. Literature Review and the Mechanism

As mentioned above, the BTH region is facing great environmental pressure in the process of rapid urbanization [12]. Pollution in this area is closely related to energy consumption [13], especially for energy consumption in industries and transportation [14]. Besides, though some of the cities in the BTH region have entered the postindustrial stage, none of them has crossed the turning point of the environmental Kuznets curve [15]. Because the BTH coordinated development strategy concerned in this paper focuses on environmental regulation, industrial upgrading, and transportation, a literature review is conducted accordingly.

First, for environmental regulation in the BTH region, recently, many studies made quantitative or qualitative analyses on its impact on energy consumption and gave some suggestions for further improvement. For example, by using a computable general equilibrium (CGE), Li et al. [16] found that, over the entire BTH area, the environmental policies could generate an average annual loss of 1.4% of gross regional product growth in the action plan scenario and of 2.3% in the enhanced action plan scenario. These results suggest that more joint measures are needed to promote energy conservation and emission reduction in the BTH region. For determining how policies and regulations support energy efficiency measure proliferation, Wang et al. [17] conducted a questionnaire survey of the enterprises in the BTH industrial transfer and found that the importance of awareness and investment priorities is great, so policy makers need to pay more attention to economic and legal tools and to appropriately increase supervision and punishment. By quantitatively analyzing the environmental policies of the BTH region, Zhang et al. [18] found that environmental regulations have direct and indirect spatial effects on industrial structures across regions and that environmental regulations have a long-term promotion effect on industrial structure upgrade and energy conservation.

Second, for industrial upgrades in the BTH region, the literature has made analyses about the effects of industrial upgrading on energy consumption for different industries or different regions. For example, by calculating the total factor energy efficiency (TFEE) of 27 industries in the BTH region, Li et al. [19] found that, because of the technological spillover effect from Beijing enterprise, Hebei has the highest total factor average energy efficiency in the production and supply of electric power and heat power industry, and Tianjin has the highest total factor average energy efficiency in the manufacture of raw chemical materials and chemical products and in the smelting and processing of ferrous metals. By measuring the energy rebound effect of industrial enterprises in the BTH region from 1996 to 2015, Li et al. [20] found that Hebei faces greater pressure to attain high energy conservation and emission reduction goals in the future than the other regions. By quantitatively analyzing the delinking indicators on industry growth and environmental pressures in the BTH region from 1996 to 2010, Wang and Yang [21] found that the carbon emissions in the BTH region were dominated by the secondary industry, which accounted for about 80% of total carbon emissions, and that the energy structure and energy intensity made significant contributions to the industrial decoupling progress. By quantitatively measuring the total factor carbon emission performance (TFCP) and the carbon emission mitigation potential (CMP) of 39 industrial sectors in the BTH region, Wang et al. [22] found that the manufacture of the nonmetallic mineral product sector and the production and distribution of electric power and heat power sector belong to the low TFCP–high CMP quadrant.

Third, for transportation in the BTH region, some studies analyzed the energy consumption and related pollutions brought by transportation development in the BTH region. For example, by using the panel data from 1995 to 2016, Guo and Meng [23] found that transportation energy intensity and the economic effect is the main factor increasing carbon dioxide emissions. They also found that the contributing factors to the carbon dioxide emission reduction in the transport sector are the energy structure effect, the freight turnover of unit industrial output effect, and the industrialization effect. By analyzing vehicular emission trends from road vehicles of the BTH region in the period 1999–2010, Lang et al. [24] found that, due to the rapid development of freight traffic, emissions of NO_X and PM_{10} kept increasing in Tianjin and Hebei. By analyzing the driving forces behind carbon emission of the BTH region from 2005 to 2013, Zhu and Li [25] found that the effect of energy intensity from the transportation sector always plays a negative role in Tianjin and Hebei but a positive one in Beijing.

How did the BTH coordinated development strategy affect industrial energy consumption in this region? The above studies focused on the environment and on sustainable development in this region. However, there is no direct literature on the comprehensive policy influence of the BTH coordinated development strategy on industrial energy intensity and related pollution emission intensities. As mentioned above, the strategy focuses on environmental regulation, industrial upgrade, and transportation; thus, we will analyze the relations between energy consumption and environmental regulations, transportation, and industrial upgrade combined with the existing literature.

The first one is environmental regulation. Environmental regulation will bring lower energy consumption for enterprises, and it can be divided into two situations based on the policy effects. One is that simple environmental regulations force a reduction of energy consumption, which may not be conducive to economic development. In the short term, it may harm the interests of enterprises, which will resist regulations, leading to weak policy effects. In the long term, it may force enterprises to upgrade their technology, but economic loss cannot be recovered [26]. The second one is to encourage industrial upgrading and technological progress while implementing environmental regulation, thus reducing energy consumption while maintaining corporate interests. Under the BTH coordinated development strategy, governments will break regional administrative restrictions; promote a revolution in energy production and consumption; promote green, circular, and low-carbon development; strengthen environmental protection and governance; and expand regional ecological space. The focus will be on the joint prevention and control of environmental pollution, the strengthening of environmental pollution control, the implementation of clean water action, the development of a circular economy and ecological protection, and plans to build some national parks and forest parks around the capital to actively tackle climate change. At present, Beijing, Tianjin, and Hebei have in-depth cooperation in various aspects such as improving coordination mechanisms, unified planning, unified legislation, unified standards, and joint law enforcement, and the results of collaborative environmental governance have been remarkable. For example, air quality in the three places has further improved, and the annual average concentration of PM2.5 has shown a downward trend. The PM2.5 average concentration in the BTH region has dropped by 46% compared with 2014, of which 85.9 $\mu g/m^3$ in Beijing dropped to 42 $\mu g/m^3$ in 2019, a decrease of 51%. Besides, in terms of ecological and environmental protection, China has supported ecological restoration in Zhangjiakou and Chengde and formulated an implementation plan for afforestation from 2015 to 2017 in the northwest ecological conservation area.

The second one is industrial transfer and upgrade. Under the BTH coordinated development strategy, the industries to be relocated and transferred from Beijing are mainly energy-intensive industries; tertiary industries like logistics bases and wholesale markets; public service sectors such as education, medical care, or training institutions; as well as some company headquarters. The transfer principle is a combination of the role of government and the role of market. In addition to Beijing and Tianjin, the central core function area of the "four areas" also includes Baoding and Langfang in Hebei province. These two cities will focus on the relocation and transfer of noncapital functions of Beijing and will take the lead in realizing interconnected development. It is worth noting that many regional cooperation projects have been completed, such as Beijing Automotive

Industry Corporation Huanghua plant project, Beijing Hyundai Motor Cangzhou plant project, Sinopec Beijing Yanshan Branch Caofeidian ten-million-ton refining project, and Tianjin Binhai–Zhongguancun science park, etc. Industrial transfer and upgrade can have an impact on energy consumption through several channels. First, enterprises transferred from Beijing, such as high-end manufacturing and the internet industry, will promote industrial upgrading and have a strong technology spillover effect, thus reducing energy consumption in surrounding cities. Second, the transfer of industries such as higher education and science and technology R&D sectors, as well as preferential policies to attract talents in Xiong'an New Area, can improve the level of human capital and can reduce energy consumption. Third, the establishment of the Hebei Free Trade Zone in 2019, the first large-scale free trade zone in China covering the three provincial-level administrative regions of Beijing, Tianjin, and Hebei, will drive the transformation and upgrade of Hebei's manufacturing industry and will reduce energy consumption by participating in international competition. Fourth, taking advantage of the industrial advantages of Beijing and Tianjin, Hebei province accelerated the formation of many industrial clusters, such as Zhangjiakou renewable energy demonstration area, Beidaihe life health industry innovation demonstration zone, Shijiazhuang high-end biomedical industry base, and Baoding and Cangzhou auto equipment manufacturing industry. Until the end of 2019, Hebei province altogether accepted 9773 enterprises transferring from Beijing and Tianjin. Actually, quite a few studies have quantitatively measured the reduction of energy consumption and emissions caused by industrial transfer and upgrade. For example, Li et al. [27] found that rationalization and upgrade of manufacturing structures mitigate CO_2 emissions during the period of 2003–2014; Wang at al. [28] demonstrated that advancement of the industrial structure has increased carbon emission efficiency in China between 2003 and 2016; Zhu et al. [29] found that the increase in the proportion of secondary industries would increase energy-related smog pollutions in 73 key cities of China during 2013–2017; and Zhang et al. [30] found that the industrial structure can reduce energy-related haze pollution through the path of rationalization in China from 2006 to 2016, etc.

The third one is transportation. The BTH region will construct the Beijing–Tianjin–Hebei intercity transportation network based on rail transit and will build the world-class aviation hub as well as the port group of Tianjin–Hebei, thus improving regional integrated transportation. First, traffic construction and development in the short term will undoubtedly increase travel demand and energy consumption, but in the long term, the effects of transportation on economic growth are pronounced. Transportation integration can lead to talent flow and economic exchange, can promote industrial-technological progress and industrial upgrade, and then can significantly improve GDP, thus reducing energy consumption per unit GDP. Second, transportation integration can shorten logistics distance and can reduce energy consumption. For example, parcels before, especially air express parcels, generally arrived in Beijing first and then transferred to Tianjin and Hebei by truck. High-speed highway construction shortens logistics distance and reduces energy consumption. Third, the green transportation system in the BTH region, including promotion of new energy public transportation and encouragement of the purchase of new energy vehicles, will also reduce fossil energy consumption. Fourth, the integrated transportation planning of the BTH region is more efficient than decentralized planning and the energy efficiency of the transportation sector is also higher. Until 2020, the BTH region initially built a one-hour economic circle connected by high-speed rail and highways, which is about an hour from Beijing to surrounding cities. By 2030, an intercity railway network with four verticals, four horizontals, and one ring will be formed. The "four verticals" include Beijing–Baoding–Shijiazhuang–Xingtai–Handan, Beijing–New Airport–Hengshui, Cangzhou–Tianji–Chengde, and Qinhuangdao–Caofeidian–Binhai–Huanghua Port. The "four horizontals" include Beijing–Tianjin–Yujiabao, Beijing–Tongzhou–Tangshan–Caofeidian, Tianjin–Bazhou–Baoding, and Shijiazhuang–Cangzhou–Huanghua Port. One ring is the intercity transportation ring of Beijing.

Based on the above analyses, the BTH coordinated development strategy may have a big impact on industrial energy and pollution intensities, but the direction is uncertain and needs to be empirically tested. This paper is different from previous studies: first, this study investigates the comprehensive impact of the BTH coordinate development strategy on industrial energy and pollution intensities and the estimation results are robust based on a number of statistical tests; second, it applies the quantile DID method to evaluate the heterogeneous impact of the strategy on industrial energy intensity in the BTH region at different quantile levels of industrial energy intensity; and third, it uses the data of industrial energy pollutions to estimate the different impacts of the strategy on the environment among different energy pollution sources. Such heterogeneous effects can help to make policy implications based on different pollution sources under the context of the BTH coordinated development strategy.

4. Data, Variables, and DID Models

4.1. Data and Variables

This paper uses the DID method to investigate the impacts of the BTH coordinated development strategy on industrial energy intensity and related pollution emission intensities in this region by comparing the implementation of this strategy before and after between the treatment group and the control group [31]. Industrial energy intensity and the pollution emission intensity are defined as the ratios of industrial energy consumption and industrial pollution emissions to the value-added of the industry.

This paper uses panel data, containing 30 cities from 2007 to 2017, which includes all 13 cities in the BTH region and 17 cities covering all cities of Henan Province. Henan is chosen as the control group because it is adjacent to the BTH region and they are similar in industrial energy structure, the sources of industrial energy pollution, and their variation trends. Another reason is that, except for Henan, other provinces around the BTH region have only a few recent years of statistics on industrial energy consumption and do not cover the years before implementation of the BTH coordinated development strategy. Although some southern Chinese provinces have related data, the statistical indicators for industrial pollution emissions are inconsistent with the BTH region and Henan province and the structures, especially for the variation trends of industrial energy and pollution emissions, are obviously far from that of the BTH region. The data of industrial fossil energy consumption and industrial value-added come from each Provincial Statistic Yearbook [32–35]. The data of industrial energy-related pollution emissions and all control variables come from the China City Statistical Yearbooks [36].

According to previous studies, all the models control for the following variables, which are expected to have impacts on industrial energy intensity and related pollution intensities in the BTH region. Urbanization is defined as the proportion of urban population in the total population and is denoted as *UR* [37], the industrial structure is defined as the ratio of service industrial value-added over GDP and is denoted as *SER* [38], per capita GDP is the natural logarithm itself and is denoted as *PGDP* [39], foreign direct investment (FDI) is defined as the share of FDI stock over GDP and is denoted as *FDI*/*GDP* [40], and R&D is defined as the share of the R&D expenditure over GDP and is denoted as *RD* [41].

4.2. Empirical Models

In this paper, the DID method will be adopted and the implementation of the BTH coordinated development strategy will be put forward as a quasi-natural experiment. Therefore, the following DID models are constructed:

$$INDEN_{it} = \beta BTH_i \cdot Post_{it} + \gamma X_{it} + \alpha_i + \psi_t + \varepsilon_{it} \quad (1)$$

$$INDWA_{it} = \beta BTH_i \cdot Post_{it} + \gamma X_{it} + \alpha_i + \psi_t + \varepsilon_{it} \quad (2)$$

$$INDSD_{it} = \beta BTH_i \cdot Post_{it} + \gamma X_{it} + \alpha_i + \psi_t + \varepsilon_{it} \quad (3)$$

$$INDST_{it} = \beta BTH_i \cdot Post_{it} + \gamma X_{it} + \alpha_i + \psi_t + \varepsilon_{it} \quad (4)$$

Formulas (1)–(4) are the DID estimation models that take time and city as fixed effects into account. In all models, i stands for the city from 1 to 30 and t stands for the year from 2007 to 2017. The dependent variables $INDEN_{it}$, $INDWA_{it}$, $INDSD_{it}$, and $INDST_{it}$ respectively denote the industrial energy intensity, industrial wastewater emission intensity, industrial sulfur dioxide emission intensity, and industrial dust emission intensity. $Post_{it}$ is the dummy variable for the processing time effect of the BTH coordinated development strategy. For $Post_{it}$, the years after 2014 are set as 1 and the previous years are set as 0. BTH_i is the dummy variable for processing the treatment group, indicating whether the city is located in the BTH region. If it is a city in the BTH region, it is set as 1; otherwise, it is 0. $BTH_i{\cdot}Post_{it}$ is the interaction term between BTH_i and $Post_{it}$, which is the core variable concerning by the DID method. Besides, X_{it} is a series of control variables that may cause changes in industrial energy intensity and related pollution emission intensities, including urbanization rate, industrial structure, per capita GDP, FDI, and R&D. ψ_t is the year fixed effect, α_i *is* the city fixed effects, and ε_{it} is the random disturbance term.

The DID method focuses on the coefficient β of the variable $BTH_i{\cdot}Post_{it}$, for which the economic implication can be explained by the impact of the BTH coordinated development strategy on industrial energy and pollution intensities. If the coefficients of β are positive and statistically significant, the BTH coordinated development strategy tends to promote industrial energy intensity and related pollution emission intensities. On the contrary, if they are negative and statistically significant, the BTH coordinated development strategy tends to restrain industrial energy intensity and related pollution emission intensities.

5. Empirical Results and Analyses

5.1. BTH Coordinated Development Strategy and Industrial Energy Intensity

5.1.1. The DID Results

The city fixed effect, year fixed effect, and city time trend effect variables are gradually added in Model 1, and the standard errors are clustered at the city level. Compared with other regions, the industrial energy intensity may have some inherent change trend rather than the BTH coordinated development strategy effect. Ignoring the underlying trend change of dependent variables in the treatment group will produce bias of missing variables and make the estimated results unreliable. The interaction item between city and time trends is added in column (2) of Table 1. This interaction item control for the likely trends in the treatment group. Please note that, in this paper, all subsequent regressions are controlled for the city and year fixed effects and there may be no repeated reporting in the subsequent tables.

Table 1. Regression results of Model 1.

Dependent Variable	***Industrial Energy Intensity***	
	(1)	**(2)**
BTH·Post	−0.050 *** (0.000)	−0.043 *** (0.000)
PGDP	0.039 *** (0.000)	0.045 *** (0.000)
SERT	−0.003 *** (0.000)	−0.006 *** (0.000)
R&D	−76.671 *** (0.000)	−80.490 *** (0.000)
FDI/GDP	−0.424 (0.140)	−0.453 (0.118)
UR	0.087 *** (0.006)	0.096 *** (0.000)
R square	0.36	0.39
Year FE	Y	Y
City FE	Y	Y
BTH * Time trend		Y
Observations	330	330

Source: Authors' estimation. Notes: p-values are in brackets * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

In Table 1, the BTH coordinated development strategy has a significantly negative impact on industrial energy intensity in this region. Listed in columns (1) and (2), the coefficients of the interaction terms are significantly negative at the 1% level. It shows that the BTH coordinated development strategy tends to restrain industrial energy intensity in this region. In addition, due to the extensive mode of rural ecological management, insufficient investment in environmental protection infrastructure, and technical limitations in Hebei Province, the rural ecological environment has been seriously polluted and destroyed, especially for the water source polluted by industrial wastewater and the soil polluted by solid waste. Therefore, attention should be paid to relevant environmental law enforcement efforts in the rural areas of this region.

As for the control variables, the regression results of FDI stock over GDP are negative but not statistically significant, indicating that FDI had no significant influence on industrial energy intensity. This is consistent with previous literature [42]. The regression results of the other control variables are consistent with theories and expectations.

5.1.2. The Quantile DID Results

In Table 2, the industrial energy intensities are divided into nine subpoints from low to high. Due to limited space, no other control variable results are shown. Based on the quantile DID method results, the BTH coordinated development strategy tends to restrain industrial energy intensity at the lower quantile levels from 0.1 to 0.4 but tends to promote industrial energy intensity at the higher quantile levels from 0.7 to 0.9. The results indicate that the BTH coordinated development strategy tends to restrain industrial energy intensity in the lower quantile level cities but tends to promote industrial energy intensity in the higher quantile level cities. The reason is perhaps that energy-intensive industries are mainly located in some cities of Hebei province and some of the industries transferred from Beijing are highly polluting, like steel companies, thus increasing the industrial energy intensity in some Hebei cities. However, cities with low energy intensity, such as Beijing and Tianjin, may optimize and upgrade their industries and may reduce their industrial energy intensity after the transfer.

Table 2. Regression results by quantile difference-in-difference (DID) method.

Quantile	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
BRI·Post	−0.095 *** (0.000)	−0.056 *** (0.000)	−0.068 *** (0.000)	−0.084 *** (0.007)	−0.154 (0.421)	0.216 (0.375)	0.066 *** (0.003)	0.062 ** (0.032)	0.163 ** (0.011)
Control variables	Y	Y	Y	Y	Y	Y	Y	Y	Y
R square	0.40	0.34	0.36	0.41	0.35	0.38	0.43	0.51	0.53

Source: Authors' estimation. Notes: p-values are in brackets * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Specifically, at the city level, Tangshan, Handan, Zhangjiakou, and Chengde of Hebei province rank high in industrial energy intensity and their industrial energy intensities rose in 2015. In the early stage, most of the transferring enterprises from Beijing to Hebei were high-energy-intensive, thus reducing air pollution in Beijing. Moreover, most of these enterprises were relocated to high-intensity industrial cities or nearby cities in Hebei province like the above ones. Therefore, how to improve the technical level of these enterprises transferred to Hebei and to eliminate backward production capacity among them must be of the utmost importance in the future. More environmental policies should be formulated to reduce energy consumption while maintaining corporate interests. For example, China can improve carbon emission trading markets in Beijing and Tianjin, can establish a new carbon emission trading market in Hebei province, and finally can realize carbon emission market integration in the BTH region.

5.2. Data Validity Analysis and Robustness Check

First, we tested whether the mean values of the dependent variable industrial energy intensity between the treatment group and the control group were equal after BTH coordinated development strategy. The null hypothesis of the mean test is that there is no significant difference. The results show that the p-value equals zero from the base period, which indicates that there is a significant difference in industrial energy intensity between the treatment group and the control group.

Second, this paper conducted a further parallel trend check before the BTH coordinated development strategy. The DID model does not require the mean values to be the same but hypothesizes that the trends between the control group and the treatment group must be the same before policy implementation. To support this assumption, we set up a year dummy variable representing different years, and the cross term *BTH·Year* represents the possibly different variation trend of energy intensity in the treatment group compared with the control group. Figure 2 indicates that the trends of these two groups do not have significant differences in all three years before implementation of the BTH coordinated development strategy. The coefficients of the dummy variables are not statistically significant in the three years before implementation of the BTH coordinated development strategy. Furthermore, from the year of implementation of the BTH coordinated development strategy, the impact of the policy on industrial energy intensity was significantly negative and gradually decreasing with the passage of time. In the three years after implementation of the BTH coordinated development strategy, the industrial energy intensity decreased by 4.25% in the year of implementation and decreased by 6.37% three years after implementation.

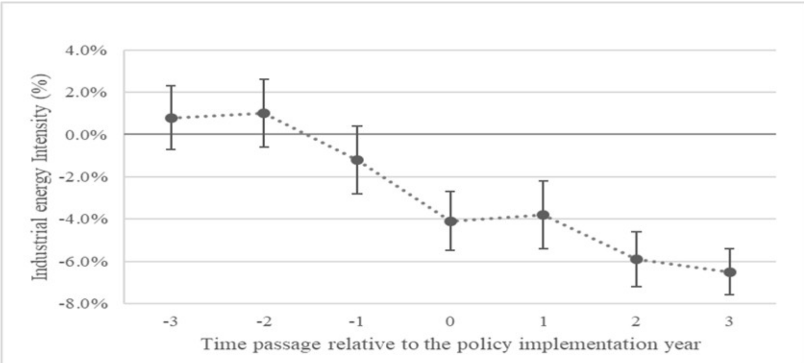

Figure 2. Parallel trend test.

Third, even if the variation trends are the same as before the policy, we still need to test other policies that may lead to different trends between the two groups. Therefore, this paper performs the placebo test by setting the policy event in a period prior to 2014 to see whether there is still a significantly negative effect. As mentioned in the previous analysis, the premise of the DID method is that there is no significantly different trend in industrial energy intensity before implementation of the policy. If the policy event is set in a period before 2014, the estimated coefficient of the core variable may be not significant. If the results are contrary to our expectations, such as significantly negative, it means that there are some potential unobserved policy factors other than the BTH coordinated development strategy that could affect industrial energy intensity in this region. To ensure the robustness of empirical results, the policy impacting years are set as 2008, 2009, 2010, 2011, 2012, and 2013 and the years after them. The corresponding estimated results are reported in Table 3. It shows that the estimated coefficients of variable *BTH·Post* are all insignificant, which proves that the DID results are robust again.

Table 3. Placebo test for robustness check.

Policy Year	2008	2009	2010	2011	2012	2013
BRI·Post	−0.033 (0.232)	0.062 (0.344)	0.025 (0.345)	−0.042 (0.563)	−0.047 (0.423)	−0.083 (0.272)
Control variables	Y	Y	Y	Y	Y	Y
R square	0.25	0.34	0.33	0.32	0.26	0.29

Source: Authors' estimation. Notes: *p*-values are in brackets.

5.3. The BTH Coordinated Development Strategy and Industrial Energy Pollution Intensities

The effects of the BTH coordinated development strategy on different sources of energy-related pollutions may vary. For example, Beijing started replacing coal with electricity for heating in 2013, followed by Tianjin and some cities of Hebei province after implementation of the coordinated development strategy, which greatly reduced industrial sulfur dioxide and dust emissions in the BTH region [43]. In this part, this paper will examine the impacts of the BTH coordinated development strategy on different sources of industrial energy-related pollution including the three wastes, which are industrial wastewater, sulfur dioxide, and dust emissions, based on the DID method.

First, in Table 4, the variable *BTH·POST* is significantly negative at the 10 percent level in Model 2, significantly negative at the 5 percent level in Model 3, and positive but insignificant in Model 4. The results indicate that the BTH coordinated development strategy tends to decrease industrial wastewater and sulfur dioxide emission intensities but may have no significant impact on dust emission intensity though the coefficient is positive. The main reason may be that, while environmental regulation and industrial upgrades have reduced the three waste emissions, some transportation infrastructure construction and operation, such as high-speed rails and highways for regional transportation development, have caused much dust pollution. Specifically, at the city level, Zhangjiakou, Baoding, Chengde, Tangshan, and other cities which are constructing expressways and high-speed railways on a large scale to build the one-hour economic circle in the BTH region may encounter more serious dust pollution issues.

Table 4. Regression results of Models 2–4.

Dependent Variable	**Model 2** *Wastewater*	**Model 3** *Sulfur dioxide*	**Model 4** *Dust emissions*
BTH·Post	−0.003 * (0.077)	−0.034 ** (0.019)	0.323 (0.282)
PGDP	0.035 *** (0.001)	0.227 *** (0.000)	0.265 ** (0.034)
SERT	−0.001 * (0.056)	−0.003 ** (0.012)	−0.014 ** (0.027)
R&D	−1.239 (0.149)	−1.781 *** (0.008)	−1.842 (0.162)
FDI/GDP	−0.113 ** (0.020)	−1.052 (0.601)	−3.852 (0.435)
UR	0.033 *** (0.001)	0.210 ** (0.048)	0.415 ** (0.025)
R square	0.35	0.33	0.22
City FE	Y	Y	Y
Year FE	Y	Y	Y
BTH * Time trend	Y	Y	Y
Observations	330	330	330

Source: Authors' estimation. Notes: *p*-values are in brackets * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

As to the countermeasures for the industrial three wastes, the most direct way to mitigate these industrial pollutions is to use clean technologies or facilities. There are some available methods for the BTH region to mitigate industrial pollutions. For example, end-of-pipe treatment technologies for the water- and energy-intensive coal-fired power industry with high emissions in the BTH region could reduce SO_2, NO_x, and dust emissions by 89%, 90%, and 88%, respectively, while consuming an average of 2% less energy and 8% more water as tradeoffs [44]. As the most polluted region in China caused by the coal-based heating system, the integration of large-scale heat pumps can potentially result in at least 9.5% energy savings and 9.28% reduced CO_2 emissions compared to the baseline of 2015 for the whole BTH region by 2030 while ensuring economic feasibility [45]. Besides, based on a slacked-based data envelopment analysis (DEA) model by cluster benchmarking of 861 wastewater treatment plants (WWTPs) in China, the technology gap ratio confirmed that large WWTPs operated more efficiently than small ones [46].

It is worth mentioning that this paper does not make an empirical analysis of the industrial solid waste pollution, which is also a crucial environmental issue in China, because some city data are not available. From the latest available data, the solid waste utilization rates of Beijing, Tianjin, and Hebei in 2019 were 80%, 98%, and 75%, respectively, which are all higher than the average of 65% in China. However, there is still potential for further improvement, particularly in Beijing and Hebei. In the process of coordinated development, corresponding environmental regulations on industrial solid waste should be strengthened to improve the utilization rate.

For the control variables, the impact of FDI stock over GDP on industrial wastewater emission intensity is significantly negative but the impacts on sulfur dioxide and dust emission intensities are insignificant. In the BTH region, foreign enterprises invest very little in energy-intensive industries but more in labor-intensive light industries which may produce mainly wastewater. As a result, the technology spillover effect can be generated in these industries and relevant enterprises will reduce industrial wastewater discharge. The impact of R&D expenditure over GDP on industrial sulfur dioxide intensity is significantly negative but the impacts on industrial wastewater discharge and dust emission intensities are insignificant. The results suggest that research spending should be focused more on reducing industrial wastewater and dust emissions for further regional sustainable development. The regression results of other control variables are consistent with the theories and expectations.

6. Conclusions, Policy Implications, and Discussions

This study investigates the different impacts of the coordinated development of the BTH region on industrial energy and pollution intensities based on the DID method and theh quantile DID method. The panel data cover industrial energy consumption and three wastes, which are industrial wastewater, sulfur dioxide, and dust emissions, from all 13 cities in the BTH region and 17 cities in Henan Province for the period 2007–2017.

The study finds that, first, based on the DID method results, the dummy variable is significantly negative at the one percent level, indicating that China's BTH coordinated development strategy on average tends to restrain regional industrial energy intensity in the BTH region. Second, based on the quantile DID method results, the BTH coordinated development strategy tends to restrain industrial energy intensity in lower quantile level (0.1–0.4) cities; still, it tends to promote industrial energy intensity in higher quantile level (0.7–0.9) cities. Third, the impacts of BTH coordinated development strategy on the environment vary among industrial wastewater, sulfur dioxide, and dust emissions. The BTH coordinated development strategy tends to decrease industrial wastewater and sulfur dioxide emission intensities because the coefficients are statistically significant at the 10 percent level and the 5 percent level but have no significant impact on dust emission intensity though the coefficient is positive.

The findings of this study can generate some policy implications. First, China should pay more attention to the green transfer and clean energy use of industries from Beijing instead of transferring outdated production capacities that may increase industrial fossil energy consumption and related pollution emissions. More attention should be given to cities that have a high energy intensity. Second, it is necessary to control dust emission during the integrated development of transportation by enforcing strict standards and by establishing an ecological traffic system, especially in the construction of expressways and high-speed railways. Third, on the premise of respecting the rules of market economy and the rules of fairness in world trade, relevant subsidy policies can be formulated with the goal of promoting environmental protection talents and of upgrading energy conservation and emission reduction technologies in Hebei, so as to change the serious unsustainability and environmental pollution problems. Fourth, standards for wastewater and sulfur dioxide emissions from some industries such as oil refining, steel making, and metallurgy can be tightened more, and governments can continue making efforts to replace coal with electricity or gas for heating and can extend the action to a wider region to reduce industrial sulfur dioxide and dust emissions, like some small towns and rural areas in Hebei province. Fifth, except for stimulating upgrade of regional industrial structures to service industry domination, the governments of some Hebei cities, like Tangshan, Handan, and Zhangjiakou, should provide more funds for energy conservation and emission reduction-related research. Sixth, the government should strengthen Beijing's role in driving industrial and technological upgrade in neighboring cities. For example, the new Free Trade Zone in Beijing established in 2020 will focus on service trade and will develop high-end industries such as the digital economy; Beijing ranked first in scientific research level on the Nature Index for five consecutive years. All of these advantages can be put to good use in the coordinated development of the BTH region. Seventh, relying on some major projects like the Xiong'an New District, Hebei free trade area, and the Beijing–Zhangjiakou 2022 Olympic Winter Games, Hebei cities should accurately position their regional comparative advantages, such as existing resources, talents, and industrial bases, to undertake related high-end industrial relocation from Beijing; to absorb the radiation effect to accelerate the upgrade of local industry and technology, thus forming the ability to retain talent and capital; and then further to own the ability to attract talent and capital, fundamentally changing the Beijing siphon phenomenon. However, it is worth noting that the central government's decision to build the Xiong'an New Area in Hebei has downgraded the national importance of Tianjin's Binhai New Area, which is the second state-level pilot zone in China after the Pudong district of Shanghai [11]. Relevant policies should be formulated to balance the relationship between the two state-level new areas so that they can complement each other. Eighth, we should specifically develop the four regional central cities, including Shijiazhuang, Tangshan, Baoding, and Handan, which will be models of environmental protection, industrial upgrade, and green transportation for neighboring node cities. Ninth, strengthening the integration of customs clearance in the BTH region can shorten customs clearance time and can reduce transportation cost of goods imported from Beijing via air transportation and those imported from Tianjin via sea transportation. At last, as the current environmental policy loses the interest of enterprises, the participation enthusiasm of industrial transfer and green upgrade is not high. The coordinated environmental regulation should be strengthened to reduce energy consumption while maintaining corporate interests, like establishing a carbon emission trading market in Hebei Province.

Although the above research gives some findings and policy implications on this topic, it should be acknowledged that, due to the limitation of the latest data, for which the time series is till 2017, whether the effects of the BTH coordinated development strategy on industrial energy and related pollutant emission intensities will continue, to this day, is unknown. Except for the DID method, other empirical techniques and data if available can be used to test some of the major aspects of the BTH coordinated development strategy, such as the impact of investment in the Xiong'an new area on energy consumption and related pollutions. If more relevant data can be obtained to form a larger control group, the DID results based on propensity score matching (PSM) can be also used to test the robustness.

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