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Environmental Regulation and Green Technology Diffusion: A Case Study of Yangtze River Delta, China

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Abstract: As an important driver of green technology innovation, the impact of environmental regulation on the diffusion of green technology remains controversial. Taking China's Yangtze River Delta (YRD) urban agglomeration, as an example, and using green patents transfer to measure green technology diffusion, this paper analyzes the effect of environmental regulation on green technology diffusion by revealing the temporal and spatial characteristics of green technology diffusion in the YRD. The results show that: (1) Green technology transfer activities in the YRD mainly take place in Shanghai, Hangzhou, Nanjing, Suzhou, and other cities. (2) Green building technology is the most demanded technology in the green technology transfer market in the YRD. (3) The direction of green technology diffusion in the YRD has changed significantly over time. In the early stage, green technologies mainly flowed to developed cities such as Shanghai, Suzhou, and Nanjing. However, in the later stage, green technologies mainly flowed from developed cities such as Shanghai, Suzhou, and Nanjing to cities with lower economic development levels (mostly located in Anhui Province). (4) The consistency of environmental regulation among cities plays an important role in promoting green technology transfer within the YRD, which is precisely what the YRD ecological green integrated development strategy emphasizes, breaking the administrative barriers between cities in the YRD and accelerating the flow of green technology between cities.

Keywords: environmental regulation; green technology diffusion; Yangtze River Delta

**Citation:** Duan, D.; Jin, H.Environmental Regulation and Green Technology Diffusion: A Case Study of Yangtze River Delta, China. *Land* **2022**, *11*, 1923. <https://doi.org/10.3390/land11111923>

Academic Editors: Wei Sun, Zhaoyuan Yu, Kun Yu, Weiyang Zhang and Jiawei Wu

Received: 30 September 2022

Accepted: 26 October 2022

Published: 28 October 2022

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1. Introduction

In the face of problems such as global climate change, deterioration of the ecological environment system, and resource and environmental stress, sustainable development supported by responsible innovation or green technology innovation has become a global economic development strategy [1–3]. However, green technology innovation activities or the applicants for green patents are highly concentrated in a few developed countries (the United States, Japan, Germany, etc.) and even in a few large multinational companies. The distribution of countries in green patent cooperation treaty (PCT) applications, released by the World Intellectual Property Organization (WIPO) in 2019, showed that the first countries to apply for green energy patents accounted for more than 76% of the total global green energy patent applications in 2019 [4]. Therefore, the collaborative development and sharing of green technologies among countries, regions, cities, and enterprises is considered as a key measure to deal with global climate change and reduce environmental pollution and ecological damage [5,6]. As shown in the report *Innovation and Diffusion of Green Technologies: The Role of Intellectual Property and Other Enabling Factors*, launched by the WIPO during a side event at UNFCCC's Bonn Climate Change Conference in June 2015, due to several market failures and other factors, the innovation and diffusion of environmental technologies pose particular problems that require a range of policy interventions. A range of policy interventions are needed to accelerate the process of green technology transfer from developed to developing countries, from developed to developing regions, and from large multinational corporations to SMEs.

From the “Beijing Declaration” to the construction of “two-oriented society”, and the ecological civilization, green development, and construction of “beautiful China”, China has become a great contributor and leader of global sustainable development, which can be verified by the rapidly growing number of green PCT applications in China [2]. However, the distribution of green technologies within China is extremely uneven, with a high concentration in a few cities along the eastern coast. Based on the above background, it has become a national strategic decision to build a market-oriented green technology innovation system that accelerates the process of green technology diffusion among regions and cities. In 2017, in order to promote the diffusion of scientific and technological achievements, the State Council of China issued the “National Technology Transfer System Construction Plan”. In 2019, China’s National Development and Reform Commission and Ministry of Science and Technology jointly issued the “Guiding Opinions on Building a Market-Oriented Green Technology Innovation System”. However, due to institutional obstacles, especially the differences in environmental regulations between regions or cities, there are still many challenges in the free flow of green technology between regions or cities.

The relationship between environmental regulation and green technology diffusion is a central topic in environmental economics, innovation economics, and science and technology management. Unlike the clear positive relationship between environmental regulation and green technology innovation, there is no consensus in the academic community on the impact of environmental regulation on green technology diffusion. As highlighted by technology gap theory, some scholars believe that regions with strong environmental regulations can stimulate the flow of green technologies from regions with weak environmental regulations to them [7]. Other scholars argue that inter-regional environmental regulation intensity differences are similar to those emphasized by multidimensional proximity theory. The more similar the environmental regulation intensity between regions is, the stronger the green technology flows between them [8]. The reason for this contradiction may be that different scholars have adopted different methods in measuring the intensity of environmental regulation and the flow of green technology, though it may also be due to the different analysis cases adopted by scholars. Just as research into enterprise green technology innovation has found, due to differences in scale, knowledge base, etc., enterprises also have great differences in the degree of adopting green technology in response to government environmental regulations [7–10].

In response to the above debate, this paper takes the Yangtze River Delta of China as a case area to explore the relationship between environmental regulation and the diffusion of green technologies. The aim of this paper is to verify the influence mechanism of the consistency of intercity environmental regulations on the flow of intercity green technology, based on revealing the spatial–temporal characteristics of intercity green technology flow in the Yangtze River Delta. The contributions of this paper are mainly two aspects. One is to measure the intercity green technology flow through intercity green patent transfer, the other is to further verify the importance of environmental regulation on green technology diffusion.

The rest of the paper is organized as follows: Section 2 reviews the relevant literature, Section 3 introduces the data sources and methods, Section 4 presents the green technology diffusion pattern and data simulation results in the YRD, and Section 5 gives the conclusions of the paper.

2. Theoretical Framework

Since the 1960s, as the contradiction between economic growth and environmental degradation has become increasingly prominent, research on green technology innovation has gradually emerged. Similar to general technology diffusion, green technology diffusion can maximize the application value of eco-innovation R&D results. At the same time, green innovation diffusion also has practical significance for improving the environmental benefits of society, practicing national ecological strategies, and achieving sustainable

development. In other words, the diffusion of green technology is even more important than the green technology itself.

A number of in-depth studies on the influencing factors of green technology diffusion with different perspectives have been conducted by scholars from different fields, including innovation theory, stakeholder theory, the resource-based view, etc. In general, the factors influencing green technology diffusion are green technology attributes (supply push), innovator capabilities, adopter capabilities (demand pull), and environmental regulations (regulatory push/pull) [11]. First of all, the attributes of green technologies can significantly impact the speed of their adoption, and, therefore, complex green technologies may spread more slowly. Secondly, innovators' capabilities also play an essential role in the diffusion of technology. Firms are usually more efficient in technology diffusion than universities, research institutions, or individuals [12]. Third, the adopters' resources and capabilities also have an effect on the diffusion of green technology, and weak production and manufacturing capabilities can prevent firms or other institutions from adopting green technologies [13].

As a driver of green innovation diffusion, environmental regulation has received the most attention. Green innovation is characterized by a double externality, implying that adopters of green technologies need to internalize the cost of reducing environmental hazards, which makes environmental regulation strongly influence the diffusion process of green innovation [14]. There are three major perspectives on the relationship between environmental regulations and green technology diffusion. Some scholars argue that strict environmental regulations at the inflow site inhibit the diffusion of green technologies, which is based on the theory of neoclassical economics that environmental regulations such as energy policies and taxes increase the cost burden of firms, stimulating the green effect paradox and inhibiting firms' incentives to adopt green technologies [15]. In addition, green technologies are usually initially developed, which means, compared with other investments, they are riskier, more uncertain, and do not yield the same corresponding benefits in the short term as existing non-green technologies [16]. At the same time, environmental standards and regulations make companies less motivated to make an effort regarding green innovation. When faced with meeting environmental standards or regulatory requirements, companies have no motivation to develop or adopt new green technologies to reduce pollution [17].

It has also been argued that environmental regulations can promote the diffusion of green technology. First, well-designed environmental regulations can stimulate the innovation compensation effect, which can positively affect green technology diffusion by compensating firms for the increased compliance costs of developing and adopting green technologies [18]; this is the famous Porter hypothesis, which has been verified by many subsequent studies [19,20]. At the same time, market-based instruments such as innovation subsidies and permits can provide a cost-effective response to environmental problems. Based on characteristics, firms can choose the most efficient way to improve their environmental performance [9]. Moreover, strict environmental regulations provide new technological opportunities and create a huge demand for green innovation. For example, some studies have found that top researchers prefer to develop environment-related offshore innovation activities in host countries with strict environmental regulation policies, as such stringent environmental regulations motivate them to localize their green innovation activities [7].

Contrary to the above two perspectives, other scholars argue that the stringency of environmental regulations does not affect the flow of green technology. Similar environment regulations between the inflowing country and the outflowing region will increase the number of green technology transfers. Dechesleprêtre analyzed data on vehicle emission standards and nonresident patents for 72 countries from 1992–2007 and found that when the regulatory standards in the inflowing region are more similar to those in the inventing country, more green technologies would flow into those countries [8].

All the above studies focus on micro- (institutions, companies) or macrolevel (countries), and microlevel studies often collect data by distributing questionnaires to companies, using the adoption rate of green energy efficient technologies [21] or the adoption of green energy technologies [8,9] as a measure of green technology flows. Macrolevel studies, on the other hand, often use cross-border patent application data as a measure of green technology flows [22]. Studies on the spatial diffusion of green technologies at the city scale are not common. This paper uses the number of green patent transfers to measure urban green technology flows. Since technology transfer is the key to innovation diffusion [23], a multilevel perspective of technology transfer studies is becoming one of the popular themes.

Patent data have higher reliability and broader coverage than questionnaire data. In addition, with the development of networks, the diffusion of green technology has shown complex network characteristics [24]. It has become a future research trend to adopt complex network theory to analyze green technology diffusion [25]. China has the largest green technology market, and, notably, the YRD is the pioneering region of green technology in China. Therefore, this paper analyzes the spatial and temporal patterns of green technology transfer in the YRD using social network analysis, which analyzes the impact of environmental regulation on green technology transfer, based on triangular green technology transfer data, and uses Quadratic Assignment Procedure (QAP) regression. The results help to clarify the following research questions:

How does the environmental regulation affect the inter-regional diffusion of green technologies in the context of regional leading markets? In what spatial pattern is the diffusion process of green technologies organized?

3. Data and Methods

3.1. Study Area

The YRD region is the intersection of the Yangtze River Economic Belt and the eastern coastal development belt, which includes Jiangsu, Zhejiang, and Anhui provinces and Shanghai, with a total of 41 cities. It is the most representative urban agglomeration in China and the top priority for China's economic development. In 2020, the YRD region generated USD 24.47 trillion in regional GDP, accounting for 24.1% of China's GDP, though the region covers only 3.6% of China's land area. Meanwhile, ecological green development has been the leading direction of economic development in the YRD region. In December 2019, the State Council of China issued the "Outline of the YRD Regional Integrated Development Plan", which explicitly proposes to strengthen the construction of a collaborative innovation industry system and strengthen the common protection and joint management of the ecological environment. Innovation-driven and green development have become the leading directions of economic development in the YRD region. In 2022, Jiangsu, Zhejiang, and Shanghai jointly issued "Several Policy Measures on Further Supporting the High-Quality Development of the YRD Ecological and Green Integrated Development Demonstration Zone", to further promote high-quality development of the YRD ecological and green integration. Under this background, remarkable achievements have been made in environmental governance, and technology transfer activities are very active in the Yangtze River Delta region, which makes the YRD region a pioneer of China's green technology. In 2020, 4868 green patents were intercity-transferred in the YRD region, accounting for 24.5% of the national total. Nationwide, green patents were transferred with the participation of cities in the YRD, accounting for 65.3% of the total.

3.2. Data Sources and Processing

Green patents are direct evidence of innovation-driven sustainable development, and its transfer reflects the flow and sharing of green innovation knowledge between regions. Meanwhile, patent transfer has a specific commercial value and may about to be used for commercial purposes. Patent transfer can also analyze the direction and spatial scope of innovation diffusion from the transferor to the transferee. Therefore, this paper uses

green patent transfer to measure green technology flow. Firstly, the data of Chinese patent transfer in 2010, 2015, and 2020 were retrieved from the Patent Information Service Platform of Intellectual Property Press (<http://search.cnipr.com/>, accessed on 13 January 2022), containing information such as patent application number, main classification number, registration effective date, rights holder before change, rights holder after change, address of rights holder before change, and address of rights holder after change. Secondly, the green patent identification system was constructed by the IPC patent classification number (including clean energy technology, greenhouse gas treatment technology, green transportation technology, green building technology, environmental management technology, and green water technology) [26], and the green patent transfer data are selected from the complete sample data. Finally, based on the information of “the address of the rights holder before the change” and “the address of the rights holder after the change,” the cities of the rights holder before the transfer of green patents and the cities of the rights holder after the transfer are identified, and the green patent transfer data related to 41 cities in the YRD are screened. The processed information of cities before and after patent transfer is used as the basic information of directional relationship nodes, and ArcGIS is used for visualization.

3.3. Methods

3.3.1. Network Construction

With cities as nodes and the number of green patents transferred between cities as edges, the weighted directed green technology diffusion network in the YRD is constructed. The green technology diffusion network mainly portrays the intercity technology transfer relationship. All nodes in the network are cities within the YRD, and its network boundary is its administrative boundary.

3.3.2. Variables Selection

The explained variable of this paper is the number of green patents that transfer from one city to another. The central explanatory variable in this paper is the intensity of environmental regulation. The established literature quantifies environmental regulation in four main ways. One is to measure environmental regulation in terms of environmental governance expenditures, such as government incentives to invest in policies [27]. The second is to measure environmental regulation in terms of pollutant emission levels or treatment levels, such as pollutant emissions or pollutant treatment rates [28]. The third is the establishment of a comprehensive evaluation system of environmental regulation to create comprehensive indicators in three dimensions: input, process, and outcome [29]. The last method is to use alternative indicators to measure environmental regulation, which is to prevent environmental regulation from being too complex [30]. Comparing the above four methods, the most reasonable method is to construct a comprehensive evaluation system of environmental regulation. However, it is difficult to apply this to city-scale studies due to data availability. In addition, it is difficult to obtain data on pollutant emission reduction expenditures at the urban scale level in China. However, official statistics on pollutant emission levels are available. Based on previous studies [28], three indicators are used in this paper, namely general industrial solid waste comprehensive utilization rate, domestic sewage treatment rate, and domestic waste harmless treatment rate, and entropy value method is used to construct the urban environmental regulation intensity index.

The study of drivers in green technology diffusion in enterprises provides a reference for selecting the control variables of intercity green technology diffusion influence factors in this paper [31]. Knowledge base theory suggests that the knowledge base of a subject largely determines its ability to acquire external knowledge [32]. In terms of green technology diffusion in enterprises, enterprises' existing green technology innovation capacity is often used as the basic variable, which determines their ability to absorb and supply green technology. Meanwhile, technology gap theory suggests that technology gaps can induce technology transfer, such as the technology transfer from developed to developing

countries [33]. Previous studies have also shown that technology gap is one of the drivers of intercity technology diffusion in China.

Environmental economics theory suggests that firm's attribute plays an important role in green technology diffusion. In intercity green technology diffusion, there will be differences in green technology diffusion due to cities' different essential characteristics. Economic development drives the transformation and upgrading of urban industrial structure, which determines what type of green technology output is high and what type of green technology is in high demand in cities. Usually, cities with mainly dominant secondary industries tend to have a higher demand for green technologies in the production and emission stages than cities with mainly dominant primary or tertiary sectors.

The government's scientific and technological support are equally important in the diffusion of green technologies. The local government's support for scientific research and education can, on the one hand, play a guiding demonstration role and, on the other hand, can reduce the pressure and risk of the enterprises' initial investment. Therefore, government support in scientific research and education can stimulate intercity green technology transfer. Human capital is key to developing green innovation capacity in cities, and it can help to improve their green innovation capacity. Meanwhile, the higher the level of human capital is, the higher the feasibility of green technology and the lower the upfront risk that enterprises take to adopt green technology.

In this paper, five control variables are constructed, which are selected from economic development level, industrial structure, human capital, knowledge base, and government support. Economic development level is measured by GDP; the industrial structure is measured by the proportion of tertiary industry to GDP; human capital is measured by the number of full-time teachers in general higher education institutions; the knowledge base is measured by the number of green technology applications in cities; and government support is measured by the scale of R&D funding investment. All of the above data are derived from the China City Statistical Yearbook.

3.3.3. Quadratic Assignment Procedure

In this paper, the impact of environmental regulation on green technology diffusion in the YRD is analyzed through the QAP regression method, which examines the relationship between the matrix of dependent variables and the matrix of multiple independent variables. The method takes relational data as the research object and has no strict requirements for independence between variables, and the regression results are more robust than conventional methods [34]. The QAP model was developed as follows.

$$R = (ERR, IND, GDP, HUM, SRE, KNO) \quad (1)$$

where R is the dependent variable, which represents the green patent transfer matrix, ERR , IND , GDP , HUM , SRE , and KNO are independent variables, which represent the environmental regulation, industrial structure, economic linkage, human capital, government support, and knowledge base, respectively.

3.3.4. Gravity Model-Based City Correlation Measurement

The green patent transfer network constructed in this paper is a directed network, i.e., the green technology diffusion between cities is differentiated and directional. Likewise, the contributions of the two cities to the spatial correlation of influencing factors such as environmental regulation and economic linkages between them are also different. It has been generally revealed that green technology innovation between cities or regions has significant spatial correlation characteristics, and the intensity of environmental regulation between cities or regions also shows similar characteristics of spatial proximity. Therefore, this paper uses a modified gravity model considering the geographic distance between cities to measure the spatial correlation degree of each factor of green technology diffusion between cities in the YRD, as in Equation (2).

$$\eta_{ij}^k = v_{ij} \frac{X_i^k X_j^k}{Geo_{ij}}, v_{ij} = \frac{X_i^k}{X_i^k + X_j^k} \quad (2)$$

where η_{ij} denotes the spatial correlation degree of city i to city j on the k factor, X denotes the driving factor of each city, Geo_{ij} denotes the geographic distance between two cities, v_{ij} is the modified empirical constant, and X contains the six driving factors selected above. Meanwhile, due to the different units of measurement of different matrices, this paper also adopts the Z-value method to standardize each influence factor network matrix, so that the mean value of each driver matrix is 0 and the standard deviation is 1. The specific variables and measurement methods are shown in Table 1.

Table 1. Variable descriptions.

Variable Name	Variable Symbols	Measurement
Spatial relevance of environmental regulation	$ERR_{i \rightarrow j}$	The three indicators of general industrial solid waste comprehensive utilization rate, domestic sewage treatment rate, and domestic garbage harmless treatment rate are selected to construct the urban environmental regulation intensity index using the entropy value method, and the spatial correlation from city i to city j in environmental regulation is measured using Equation (2).
Economic linkage spatial relevance	$GDP_{i \rightarrow j}$	Use city GDP to represent the level of economic development of cities and use Equation (2) to measure the spatial correlation from city i to city j in terms of economic development.
Spatial correlation of industrial structure	$IND_{i \rightarrow j}$	Use the ratio of tertiary industry output value of cities to represent the industrial structure of cities, and use Equation (2) to measure the spatial correlation from city i to city j in terms of industrial structure.
Spatial correlation of human capital	$HUM_{i \rightarrow j}$	The number of university faculty in the city is used to represent the human capital of the city, and the spatial correlation from city i on city j in terms of human capital is measured using Equation (2).
Government support spatial relevance	$SRE_{i \rightarrow j}$	Using the scale of city R&D expenditure to represent the city government financial support, and using Equation (2) to measure the spatial correlation from city i to city j , in terms of government support.
Knowledge base spatial relevance	$KNO_{i \rightarrow j}$	Use the city green patent applications to represent the city knowledge base, and use Equation (2) to measure the spatial correlation from city i to city j in the knowledge base.

4. Results

4.1. Mapping the the Diffusion of Green Technology in YRD

From 2010 to 2020, the number of green patents transferred in the YRD region increased rapidly, from 101 in 2010 to 4868 in 2020. The number of cities participating in green technology transfer in the area also increased from 28 to 41. Over the past 10 years, the pattern of green technology transfer in the YRD has developed from point-like scattering to forming a network in the east and spreading to the west and north. The flow of patents has shifted from clustering in the east to spreading from the east to the central and western regions (Figure 1 and Table 2).

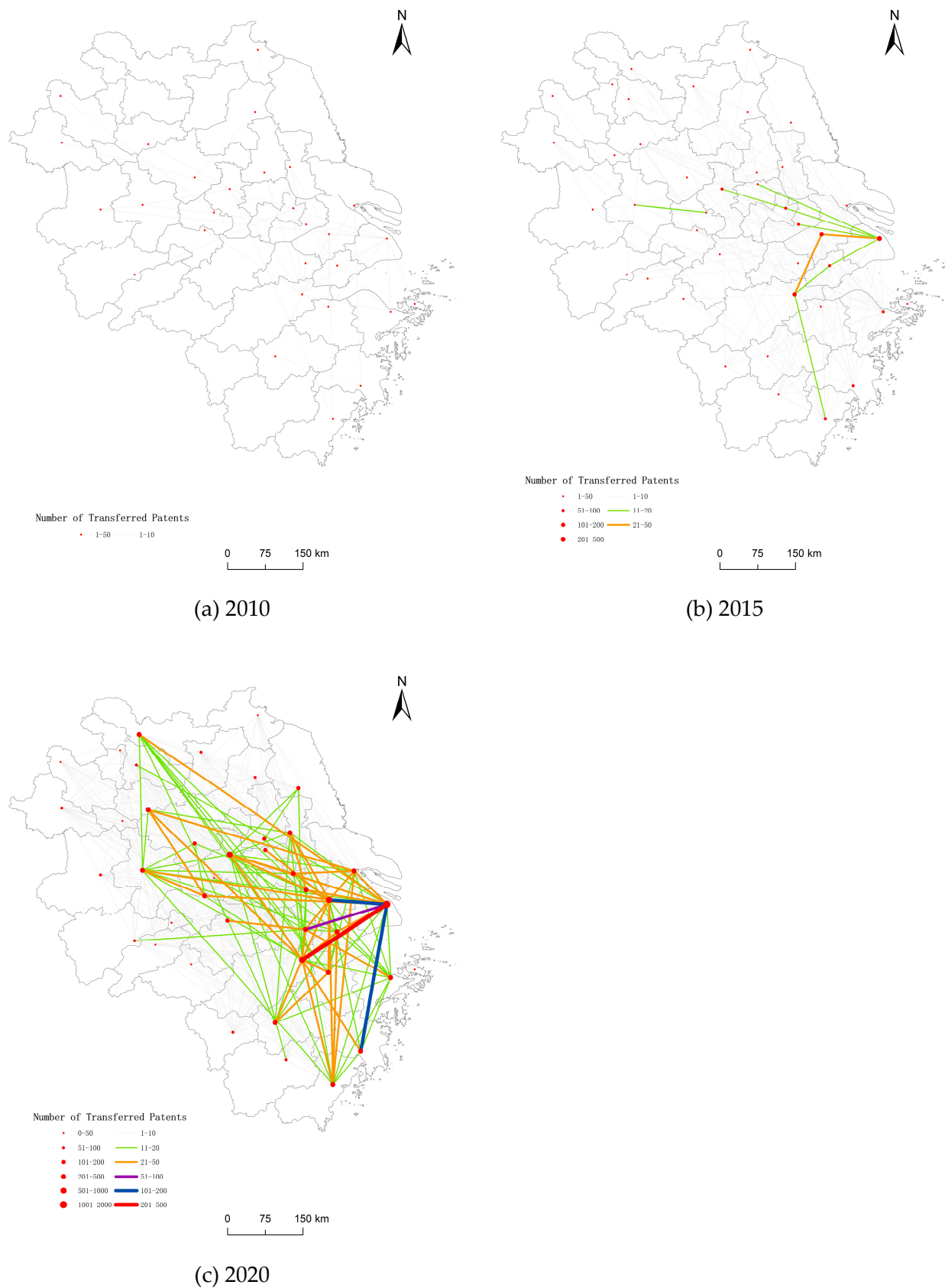


Figure 1. Green technology diffusion in YRD from 2010 to 2020. Data source: Patent Information Service Platform of Intellectual Property Press. Available online: <http://search.cnipr.com/pages!advSearch.action> (accessed on 13 January 2022).

Table 2. Top 10 intercity links of green technology transfer in YRD.

Order	2010			2015			2020		
	Transfer Out	Transfer In	Number	Transfer Out	Transfer In	Number	Transfer Out	Transfer In	Number
1	Suzhou	Shanghai	10	Suzhou	Shanghai	34	Shanghai	Hangzhou	209
2	Shanghai	Suzhou	10	Hangzhou	Suzhou	33	Shanghai	Taizhou	198
3	Changzhou	Wuxi	7	Shanghai	Suzhou	22	Shanghai	Suzhou	130
4	Shanghai	Jiaxing City	5	Zhenjiang	Shanghai	15	Shanghai	Huzhou City	51
5	Jinhua	Taizhou	5	Changzhou	Shanghai	14	Nanjing	Changzhou	50
6	Ningbo	Shanghai	4	Wuxi	Shanghai	13	Shanghai	Jiaxing City	50
7	Millipore	Ma'anshan City	4	Changzhou	Nanjing	13	Nanjing	Suzhou	49
8	Wenzhou	Suzhou	3	Hangzhou	Jiaxing City	13	Suzhou	Shanghai	48
9	Taizhou City	Suzhou	3	Ma'anshan City	Hefei	13	Hangzhou	Jiaxing City	47
10	Shanghai	Hangzhou	3	Wenzhou	Hangzhou	13	Hangzhou	Huzhou City	46

Data source: Patent Information Service Platform of Intellectual Property Press. Available online: <http://search.cnipr.com/pages!advSearch.action> (accessed on 13 January 2022).

In 2010, the volume of green technology transfer and the number of participating cities in the YRD region were 101 and 28, respectively, with 19 cities transferring out of green technology, 18 cities transferring into green technology, and 16 cities absorbing and spreading out green technology. In 2015, the volume of green technology transfer and the number of participating cities in the YRD region were 711 and 40, respectively, with 38 cities transferring out of green technology, 39 cities transferring into green technology, and 37 cities absorbing green technology as well as spreading it outward. In 2020, the number of green technology transfers soared to 4868, and all 41 cities in the YRD region participated in green technology transfers.

In terms of green technology transfer volume, Shanghai, Suzhou, Hangzhou, Nanjing, and Wuxi occupied the top five positions in 2010, with Shanghai ranking first with 39 green patents transferred (22 transferred out and 12 transferred in); Suzhou ranked second with 29 green patents transferred (10 transferred out and 19 transferred in); and Hangzhou ranked third with 20 green patents transferred (12 transferred out and 8 transferred in). In 2015, the top 10 positions were occupied by Shanghai and cities in Zhejiang and Jiangsu provinces. Shanghai ranked first, with 207 transferred green patents (94 transferred out and 113 transferred in); Suzhou ranked second with 150 transferred green patents (71 transferred out and 79 transferred in); and Hangzhou ranked third with 140 transferred green patents (92 transferred out and 48 transferred in). In 2020, 9 of the top 10 positions were taken by cities in Shanghai, Zhejiang, and Jiangsu. Shanghai ranked first, with 1157 transferred green patents (865 transferred out and 292 transferred in); Hangzhou overtook Suzhou and ranked second with 816 transferred green patents (447 transferred out and 369 transferred in); Suzhou ranked third with 796 transferred green patents (341 transferred out and 455 transferred in); and Hefei, in Anhui province, ranked first with 392 transferred green patents (270 transferred out and 122 transferred in). In 2010 and 2015, Shanghai, Hangzhou, and Suzhou occupied the core position of intercity green technology transfer in the YRD, with the volume of green technology transfer in these three cities accounting for more than 70% of the total intercity green technology transfer in the YRD. In 2020, Shanghai became the sole core of the network, accounting for 23.8% of the total green technology transfer volume in the YRD.

In terms of intercity green technology transfer relationship, in 2010, the strength of innovation linkage between cities was generally weak, and the strongest linkage was between Shanghai and Suzhou, with 10 of the 22 green patents transferred from Shanghai being transferred to Suzhou, and all 10 green patents transferred from Suzhou were transferred to Shanghai. This was followed by Changzhou and Wuxi, with 7 of the 10 green patents transferred from Changzhou being transferred to Wuxi. In 2015, Suzhou had a strong relationship with Shanghai and Hangzhou. Overall, 34 of the 71 green patents transferred from Suzhou were transferred to Shanghai, 33 of the 92 green patents transferred from Hangzhou were transferred to Suzhou, and 22 of the 94 green patents transferred from Shanghai were transferred to Suzhou. In addition, five pairs of cities, in the top 10 intercity links of green technology transfer in the YRD region, are cities in Shanghai and Jiangsu provinces, indicating that the links between Shanghai and Jiangsu Province in the YRD

region are closer, and the green ecological integration of the YRD is yet to be further developed. In 2020, 209 of the 865 green patents transferred from Shanghai were transferred to Hangzhou, 198 were transferred to Taizhou, and 130 were transferred to Suzhou, which is also in the top three intercity links of green technology transfer in the YRD region. In addition, four pairs of cities, in the top 10 intercity links in the YRD region, are cities in Shanghai and Zhejiang Province, and two pairs are cities in Shanghai and Jiangsu Province, indicating that Shanghai is still the core of green technology transfer in the YRD region. However, compared with 2015, the relationship between Shanghai and Zhejiang Province is stronger. The closeness with Jiangsu Province has slightly decreased, and the green ecological integration in the YRD still needs further development.

In terms of spatial distribution, in 2010, the amount of intraregional green technology transfer in the YRD was small, and the network was sparse. In 2015, firstly, the network of green technology transfer in the eastern part of the YRD began to form a network. Secondly, the dominant position of YRD intraregional green technology transfer was occupied by Shanghai, Suzhou, and Hangzhou, and among 209 pairs of intraregional green technology transfer relationships, 86 pairs involved three cities, namely Shanghai, Suzhou, and Hangzhou. In addition, intraregional green technology transfer at this stage mostly showed clustering to the east in terms of direction. By 2020, the eastern YRD green technology diffusion network continued to grow and dominated the whole YRD region, but the intercity green technology transfer in this stage was opposite to that in 2015, showing patterns from east to west and from east to south, which were mainly transfers of green patents from Shanghai, Nanjing, Suzhou, and other cities to the west. In general, cities with higher innovation linkage intensity in these three years are basically centered on Shanghai, Suzhou, Hangzhou, Nanjing, Ningbo, Jiaxing, and cities with higher economic development levels. The intensity of green patent transfer linkage among cities generally shows the characteristics of intensiveness in the southeast and sparseness in the northwest. In addition, the direction of patent flow shifts from clustering in the east to spreading from the east to the central and western regions.

4.2. Model Estimation Results

Since the number of green patent transfers in the YRD in 2010 was so small, which would affect the robustness of the model, we only used the green patent data of 2015 and 2020 for regression. Table 3 shows the QAP regression results of the factors influencing green technology diffusion in the YRD in 2015 and 2020. The coefficients of environmental regulation are all positive and all significant at the 1% level, indicating that the stronger the spatial linkage of environmental regulation is, the greater the amount of green technology transfer between cities. In other words, our study shows that a high level of similarity in environmental regulations can facilitate green technology transfer within the YRD region. As the largest economic growth pole in China, the YRD region, which contains Shanghai, Jiangsu, and Zhejiang provinces, as early as 2004, jointly issued the Declaration on Regional Cooperation in the YRD to incorporate environmental cooperation into the regional economic integration strategy and make full use of market instruments to improve and develop environmental regulations. In 2007, 16 cities in the economically developed eastern and southern YRD signed the YRD Regional Cities (Changzhou) Cooperation Agreement, which established a general framework for the YRD to facilitate ecological compensation mechanisms. In 2016, the three provinces and one city of the YRD jointly published the Regional Linkage of Environmental Law Enforcement in the YRD Region Initiative to make cooperation in supervising environmental violations involving water, air and hazardous waste. In 2019, China issued the “Outline of the YRD Regional Integrated Development Plan”, which prioritizes adherence to ecological and environmental protection and places great importance on the protection and restoration of the ecological environment. It can be understood that the environmental regulations in the YRD region are gradually improving, given the two main environmental regulations of incentives and penalties. Since then, the environmental regulations of the three provinces and one city in the YRD have a tendency

toward integration, and the collaborative environmental management has become increasingly effective, which also promotes the intraregional flow of green technologies in the YRD, to a certain extent.

Table 3. QAP regression of influencing factors of green technology transfer in YRD.

Variables	2015		2020	
	Unstandardized Coefficient	Standardized Coefficient	Unstandardized Coefficient	Standardized Coefficient
ERR	0.533281 ***	0.269436 ***	2.120452 ***	0.216643 ***
GDP	1.685275 ***	0.866144 ***	4.569788 ***	0.474893 ***
IND	−0.889848 ***	−0.456892 ***	−3.562693 ***	−0.369811 ***
HUM	0.350277 ***	0.180017 ***	2.439780 ***	0.253540 ***
SRE	−0.145534 **	−0.074759 **	0.055620	0.005777
KNO	−0.893463 ***	−0.459295 **	−1.782901 ***	−0.185294 ***

Note: *** $p < 0.1$, ** $p < 0.05$.

In addition, we have some other findings. Urban economic development linkage promotes green technology flow within the YRD region. The stronger the urban economic development level linkages are, the more economic cooperation there is, which to a certain extent widens the opportunities for intercity green technology exchange and cooperation, thus promoting green technology transfer. Second, tertiary industry linkages did not promote intercity green technology transfer, while they had a suppressive effect. The possible reason is that green building technology is the most applied green patent category in China, and, when analyzing the spatial and temporal pattern of green technology flow in the YRD, we found that green building technology is the most popular technology in the market, which is why the growth of tertiary industry, represented by the information and communication industry and scientific research, does not promote green technology flow.

Third, human capital linkage can promote green technology transfer within the YRD region. Talent is the engine of scientific and technological progress and plays a prominent role in enhancing green technology innovation capacity. When educational human capital accumulates to a certain level, especially when the technological innovation effect of advanced educational human capital comes into play, human capital linkage would have a positive impact on green technology transfer in the YRD. Fourth, the government's scientific research support has negative influence on green technology transfer in the YRD region. The government's financial support for education and scientific research mainly promotes scientific research, rather than the specific application of green technology results. Therefore, more government support for scientific research and education does not necessarily facilitate green technology transfer. Fifth, there is a significant negative effect of innovation capacity linkage on green technology in the YRD. After 2015, although the green patent transfer among top cities, such as Shanghai and Suzhou, occupied the top position, many cities with a low number of green patent applications also had technology transfers with top cities. For example, in 2020, top cities such as Shanghai, Nanjing, Hangzhou, and Wuxi mainly played the suppliers' role in the patent transfer network, while cities with weak knowledge bases such as Anqing, Fuyang, and Bozhou obtained many green patents from top cities. In this regard, innovation capacity linkage does not impede intercity green technology transfer. This confirms the correctness of technology gap theory, which induces technology transfer to occur, i.e., cities with strong green innovation capabilities will transfer green technologies to cities with weaker green innovation capabilities.

5. Conclusions and Discussion

The relationship between environmental regulation and green technology diffusion is currently a core research topic in the environmental innovation field. In this paper, we measured the intercity green technology diffusion by the number of green patent transfers and carved the spatial and temporal patterns of green technology flows in the YRD. Then,

we analyzed the impact of environmental regulation on green technology transfer with the help of the QAP model, from which we summarized the following findings.

First, from 2010 to 2020, green technology transfer in the YRD region mainly occurred in Shanghai, Hangzhou, Shaoxing, Suzhou, and Nanjing. The intensity of the green patent transfer linkage between cities generally shows the characteristics of intensiveness in the southeast and sparseness in the northwest, while the direction of patent flow shifts from clustering in the east to spreading from the east to the central and western regions. From the perspective of green patents, the ecological green integration of the YRD has not yet been realized and needs to be further developed [35]. Cities in the east and south lead the development of green technology transfer in the YRD. Meanwhile, the western and northern regions, such as Anhui Province, are the key “poverty alleviation” areas of green technology integration in the YRD.

Second, the regression results show that environmental regulation facilitates green technology diffusion within the YRD region. This is because the YRD region, as the leader of green development in China, reached a regional environmental governance agreement as early as 2004. Since then, environmental regulation regulations in the YRD region have been gradually improved. In 2019, the integrated green regional development of the YRD region was promoted to a national strategy. The YRD region has been at the forefront of green development in China, and its relevant laws and regulations are more mature, which is an important reason why environmental regulations play a strong role in promoting green technology diffusion within the YRD region.

In addition, we have some other interesting findings. First, tertiary sector linkages have a negative impact on the flow of intercity green technology. Green building technologies are the most dominant technologies in the market, so the growth of the tertiary sector, represented by the information and communication industry and scientific research, does not promote the flow of green technology. Secondly, human capital linkage has a facilitating effect on green technology transfer within the YRD region, because, when educational human capital accumulates to a certain level, the technological innovation effect of advanced educational human capital will, especially, come into play. Third, innovation capability linkage shows a negative effect on green technology transfer in YRD, which confirms the technology gap theory. Fourth, government research support has a negative effect on green technology flow within the YRD region.

In response to the above findings, we offer some suggestions. Firstly, the Yangtze River Delta region needs to increase green technology innovation investment collectively; the top cities of green technology innovation, especially, should help cities with weaker green technology innovation capacity through a multitype help mechanism, to narrow the technology gap between cities, while enhancing cities’ green technology absorption and conversion capacity. Secondly, it is necessary to build the central role of Shanghai’s green technology innovation in China by cultivating green technology innovation engine enterprises, improving its green technology innovation potential, and enhancing the radiation and driving ability of Shanghai on green technology innovation in the Yangtze River Delta. Finally, it is crucial for the Yangtze River Delta region to tailor (dynamically adjust) environmental regulations to local conditions. The Yangtze River Delta collaborative governance system should be further improved to avoid the “race to the bottom” that is caused by excessive differences in the intensity of environmental regulations between cities.

There are still some limitations in our study. First, it is, relatively, a single method to measure the environmental regulation of cities from the perspective of pollutant treatment, by synthesizing only the comprehensive utilization rate of general industrial solid waste, domestic sewage treatment rate, and harmless domestic waste treatment rate into comprehensive indicators, so building a richer environmental regulation evaluation index system is a future direction to be explored. Secondly, although China’s green patents has been classified into six types according to the existing literature, there are still some environmental technologies that have not been taken into consideration, such as adsorption and cooling technology, advanced combustion technology, and emission reduction

technology, so a broader green patent identification system should be established in the future. Thirdly, enterprises have a dominant position in green technology innovation and transfer. Combining enterprise heterogeneity (scale, industry, etc.) with the spatial and temporal characteristics of green technology diffusion and analyzing the influence of environmental regulation on the green technology transfer between enterprises and industries of different scales is the next issue to be studied. Finally, although we have divided the green technology categories, we have not explored the spatial and temporal characteristics of green technology transfer in each category or the influence of environmental regulation on the diffusion of green technology in different categories, which are also topics that need to be studied in the future.

Author Contributions: Conceptualization, D.D.; methodology, D.D. and H.J.; software, H.J.; validation, D.D.; formal analysis, H.J.; investigation, D.D.; resources, D.D.; data curation, D.D.; writing—original draft preparation, H.J.; writing—review and editing, D.D.; visualization, H.J.; supervision, D.D.; project administration, D.D.; funding acquisition, D.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 42271186, and the MOE (Ministry of Education in China) Project of Humanities and Social Sciences, grant number 19YJC790023.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Du, K.; Cheng, Y.; Yao, X. Environmental regulation, green technology innovation, and industrial structure upgrading: The road to the green transformation of Chinese cities. *Energy Econ.* **2021**, *98*, 105247. [CrossRef]
2. Kalogiannidis, S.; Kalfas, D.; Chatzitheodoridis, F.; Papaevangelou, O. Role of crop-protection technologies in sustainable agricultural productivity and management. *Land* **2022**, *11*, 1680. [CrossRef]
3. Xu, N.; Zhao, D.; Zhang, W.; Zhang, H.; Chen, W.; Ji, M.; Liu, M. Innovation-driven development and urban land low-carbon use efficiency: A policy assessment from China. *Land* **2022**, *11*, 1634. [CrossRef]
4. WIPO. PCT Yearly Review 2020—Executive Summary. Available online: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_901_2021_exec_summary.pdf (accessed on 29 September 2020).
5. Brant, J. Green technology diffusion: Insights from industry. *WIPO Mag.* **2014**, *1*, 6–11.
6. Glachant, M. *Greening Global Value Chains: Innovation and the International Diffusion of Technologies and Knowledge*; OECD Green Growth Papers, No. 2013/05; OECD Publishing: Paris, France, 2013.
7. Marin, G.; Zanfei, A. Does host market regulation induce cross-border environmental innovation? *World Econ.* **2019**, *42*, 2089–2119. [CrossRef]
8. Dechezleprêtre, A.; Neumayer, E.; Perkins, R. Environmental regulation and the cross-border diffusion of new technology: Evidence from automobile patents. *Res. Policy* **2015**, *44*, 244–257. [CrossRef]
9. Milliman, S.R.; Prince, R. Firm incentives to promote technological change in pollution control. *J. Environ. Econ. Manag.* **1989**, *17*, 247–265. [CrossRef]
10. Woerter, M.; Stucki, T.; Arvanitis, S.; Rammer, C.; Peneder, M. The adoption of green energy technologies: The role of policies in Austria, Germany, and Switzerland. *Int. J. Green Energy* **2017**, *14*, 1192–1208. [CrossRef]
11. Hojnik, J.; Ruzzier, M. What drives eco-innovation? A review of an emerging literature. *Environ. Innov. Soc. Trans.* **2016**, *19*, 31–41. [CrossRef]
12. Wilson, C.; Grubler, A.; Bento, N.; Healey, S.; De Stercke, S.; Zimm, C. Granular technologies to accelerate decarbonization. *Science* **2020**, *368*, 36–39. [CrossRef]
13. McCarthy, I.P.; Ruckman, K. Licensing speed: Its determinants and payoffs. *J. Eng. Technol. Manag.* **2017**, *46*, 52–66. [CrossRef]
14. Laursen, K.; Leone, M.I.; Torrisi, S. Technological exploration through licensing: New insights from the licensee's point of view. *Ind. Corp. Chang.* **2010**, *19*, 871–897. [CrossRef]
15. De Marchi, V. Environmental innovation and R & D cooperation: Empirical evidence from Spanish manufacturing firms. *Res. Policy* **2012**, *41*, 614–623.
16. Hans-Werner, S. Public policies against global warming: A supply side approach. *Int. Tax Public Financ.* **2008**, *15*, 360–394.
17. Barbieri, N.; Ghisetti, C.; Gilli, M.; Marin, G.; Nicolli, F. A survey of the literature on environmental innovation based on main path analysis. *J. Econ. Surv.* **2016**, *30*, 596–623. [CrossRef]
18. Jaffe, A.B.; Stavins, R.N. Dynamic incentives of environmental regulations: The effects of alternative policy instruments on technology diffusion. *J. Environ. Econ. Manag.* **1995**, *29*, S43–S63. [CrossRef]

19. Porter, M.E.; Van der Linde, C. Green and competitive: Ending the stalemate. *Harv. Bus. Rev.* **1995**, *73*, 5.
20. Lambertini, L.; Tampieri, A. Vertical differentiation in a cournot industry: The Porter hypothesis and beyond. *Resour. Energy Econ.* **2012**, *34*, 374–380. [[CrossRef](#)]
21. Murty, M.N.; Kumar, S. Win-win opportunities and environmental regulation: Testing of porter hypothesis for Indian manufacturing industries. *J. Environ. Manag.* **2003**, *67*, 139–144. [[CrossRef](#)]
22. Stucki, T.; Woerter, M. Intra-firm diffusion of green energy technologies and the choice of policy instruments. *J. Clean Prod.* **2016**, *131*, 545–560. [[CrossRef](#)]
23. Shi, Q.; Lai, X. Identifying the underpin of green and low carbon technology innovation research: A literature review from 1994 to 2010. *Technol. Forecast. Soc. Chang.* **2013**, *80*, 839–864. [[CrossRef](#)]
24. Fan, R.; Dong, L.; Yang, W.; Sun, J. Study on the optimal supervision strategy of government low-carbon subsidy and the corresponding efficiency and stability in the small-world network context. *J. Clean Prod.* **2017**, *168*, 536–550. [[CrossRef](#)]
25. Wang, L.; Zheng, J. Research on low-carbon diffusion considering the game among enterprises in the complex network context. *J. Clean Prod.* **2019**, *210*, 1–11. [[CrossRef](#)]
26. Duan, D.; Xia, Q. Does environmental regulation promote environmental innovation? An empirical study of cities in China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 139. [[CrossRef](#)] [[PubMed](#)]
27. Pearce, D.; Palmer, C. Public and private spending for environmental protection: A cross-country policy analysis. *Fisc. Stud.* **2010**, *22*, 403–456. [[CrossRef](#)]
28. Zhao, X.; Sun, B. The influence of Chinese environmental regulation on corporation innovation and competitiveness. *J. Clean Prod.* **2016**, *112*, 1528–1536. [[CrossRef](#)]
29. Sauter, C. How Should We Measure Environmental Policy Stringency? In *A New Approach*; IRENE Working Papers; IRENE Institute of Economic Research: Neuchatel, Switzerland, 2014; pp. 14–101.
30. Keller, W.; Levinson, A. Pollution abatement costs and foreign direct investment inflows to US states. *Rev. Econ. Stat.* **2002**, *84*, 691–703. [[CrossRef](#)]
31. Zeng, Y.; Dong, P.; Shi, Y.; Wang, L.; Li, Y. Analyzing the co-evolution of green technology diffusion and consumers' pro-environmental attitudes: An agent-based model. *J. Clean Prod.* **2020**, *256*, 120384. [[CrossRef](#)]
32. Crescenzi, R.; Gagliardi, L. The innovative performance of firms in heterogeneous environments: The interplay between external knowledge and internal absorptive capacities. *Res. Policy* **2018**, *47*, 782–795. [[CrossRef](#)]
33. Hong, J.; Zhou, C.; Wu, Y.; Wang, R.; Marinova, D. Technology Gap, Reverse technology spillover and domestic innovation performance in outward foreign direct investment: Evidence from China. *China World Econ.* **2019**, *27*, 1–23. [[CrossRef](#)]
34. Doreian, P.; Conti, N. Social context, spatial structure and social network structure. *Soc. Netw.* **2012**, *34*, 32–46. [[CrossRef](#)]
35. Duan, D.; Zhang, Y.; Chen, Y.; Du, D. Regional Integration in the Inter-City Technology Transfer System of the Yangtze River Delta, China. *Sustainability* **2019**, *11*, 2941. [[CrossRef](#)]