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How Urban Environmental Health Risk Management Influences Industrial Upgrading in China: A Historical Review of Academic Literature

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Abstract

In the context of the global dual carbon transition and sustainable development, strengthening urban environmental regulations and promoting healthy and orderly urban growth have become crucial for driving the transformation of national economic momentum and achieving high-quality development in the future. Among these, the issue of urban environmental health risks and their impact on urban industrial upgrading has garnered increasing attention from the academic community. This paper approaches the topic from a historical academic perspective, meticulously tracing the evolution of urban environmental health risk management policies in China, the world's largest developing country. It analyzes the characteristics of these policies and their mechanisms affecting industrial upgrading, elucidating how this distinctive environmental regulation strategy serves to reshape urban industrial momentum. The aim is to provide valuable insights for other developing countries to strengthen ecological control measures and implement more scientifically-based composite urban environmental regulation strategies.

Keywords

Urban Environmental Health Risk Management, Industrial Upgrading, China, Academic History

1. Introduction

Environmental health risk management is a key issue in the global governance system of the 21st century. In 1992, the United Nations' "Agenda 21" explored the topics of environmental protection and the enhancement of human health in depth, urging the integration of environmental and developmental issues into the decision-making process; Subsequently, the United Nations deepened the discussion on related issues through the "Millennium Declaration" released in 2000 and the Sustainable Development Goals (SDGs) proposed in 2015. The increasing importance of environmental health risk management is underscored by a profound transformation in human development models. This marks a shift in environmental health risk management from merely addressing environmental health risks to becoming a core development element closely related to economic growth, industrial transformation, and human well-being.

Entering the 21st century, China's rapid urbanization and industrialization have facilitated industrial agglomeration and economic growth, transforming cities into dual focal points for environmental health and the demands of industrial upgrading. To this end, the Chinese government has begun implementing proactive urban environmental health risk management in an effort to continuously promote industrial upgrading. Whether it is the "Two Mountains" concept, the "Healthy China 2030" plan, or the new development concepts and practices of new productive forces, it is evident that China's urban environmental health risk management system has achieved a crucial leap from pollution control measures to the driving force for industrial upgrading. Currently, the concept of urban environmental health risk management is becoming increasingly rich, encompassing not only governance-oriented urban environmental regulations but also preventive-oriented urban health regulations. Its impact on industrial upgrading is both comprehensive and complex, and the specific mechanisms of its implementation remain widely debated. Based on existing research, most studies focus on issues related to urban environmental regulation, with a notable lack of research on urban health regulations concerning industrial upgrading. Additionally, there is a significant deficiency in comprehensive studies that explore the impact and mechanisms of integrated urban environmental health risk management on industrial upgrading. In light of this, this paper focuses on the research theme of urban environmental health risk management and industrial upgrading. Based on an in-depth analysis of the concepts of environmental health risk management and industrial upgrading, it provides a comprehensive review and summary of the current academic discourse regarding the positive, negative, and ambiguous impacts, as well as the multiple mechanisms of urban environmental health risk management on industrial upgrading, thereby laying a theoretical foundation for subsequent related studies.

2. Characteristics of Urban Environmental Health Risks in China and Governance Approaches

1) Characteristics of Urban Environmental Risks in China

The management of environmental health risks in Chinese cities is a collaborative governance process involving multiple stakeholders, centered on safeguarding residents' health and achieving a synergistic development of "environment-health-economy" during the urbanization process. This process is characterized by "government leadership + business responsiveness + public participation" (Bi et al., 2025); It is based on the WHO risk assessment framework, U.S. EPA management standards, and China's "Technical Guidelines for Environmental Health Risk Management" (HJ25.1) as the scientific foundation. The approach systematically identifies traditional and emerging risk sources in urban environments—both physical and chemical. Employing risk monitoring, exposure assessment, and health effect evaluation, it weighs socio-economic and technical factors to develop and implement a comprehensive strategy encompassing "policy regulation-technical application-early warning-public communication"; Its core lies in transcending the traditional environmental regulation model of "government-centric oversight and end-of-pipe pollution control." This involves integrating public health dimensions and reinforcing a preventive orientation, achieving a comprehensive upgrade from "passively responding to pollution" to "actively controlling health risks," and moving from "single governance" to "multifaceted collaborative assurance" (Liu et al., 2019). Currently, under the dual drivers of urbanization and global climate change, urban environmental risks in China exhibit key characteristics of complexity, spatial heterogeneity, and diversified drivers. Firstly, the phenomenon of complex pollution has become widespread, with the independent effects of single pollutants gradually being replaced by the synergistic effects of multiple factors. Firstly, our empirical research results in Xi'an demonstrate that urban environmental risks are no longer confined to single atmospheric pollutants such as PM2.5 and PM10; instead, they are characterized by the compounded effects of heatwaves and air pollution. This interaction, arising from the accumulation of hazard factors, exposure levels, and vulnerabilities, creates a more complex field of environmental risks (Jiang et al., 2022). The study of the spatial and temporal distribution of heavy metals in urban dust in Hangzhou further corroborates this characteristic, showing significant differences in the bioavailability of lead (Pb) and cadmium (Cd) across different functional areas, along with clear seasonal fluctuations. Specifically, the bioavailability of Pb increases during the autumn and winter, while Cd exhibits higher activity in spring and autumn. This spatial and temporal heterogeneity complicates risk management (Guan et al., 2024). Secondly, spatial heterogeneity is another significant characteristic of urban environmental risks in China, manifesting at both the regional scale and within the urban landscape itself. Research on environmental governance performance in the three major river basins indicates a gradient variation in environmental risk levels among the Pearl River, Yellow River, and Yangtze River basins, with the Pearl River basin exhibiting the best performance. Additionally, cities within the basin have developed a "multi-core" distribution pattern (Xu et al., 2025). The case of Beijing reveals the differential drivers of risk within the city: the expansion of impermeable surfaces is the primary driver of ecological risk, particularly significant in areas where the impermeable surface ratio is between 40% and 70%. Furthermore, the influence of population density and GDP intensity shows a staged transition, with GDP intensity surpassing that of population density after 2010 (Urban Ecological Risk and Management Research Group, Institute of Urban Environment, Chinese Academy of Sciences, 2023).

Lastly, the diversification and interaction of risk drivers constitute the third major characteristic of environmental risks. The rigid growth of energy consumption and pollutant emissions serves as the foundational driving factors, directly leading to the deterioration of air quality. Additionally, the urban heat island effect, compounded by global warming, further amplifies the risks associated with high temperatures. Human activity interventions have made the mechanisms driving risks increasingly complex. The multi-sourced inputs from traffic, coal combustion, and other factors have resulted in the "multi-point diffusion and concentrated outbreaks" of heavy metal accumulation in urban dust. Notably, pigment components in paints have been found to have a significant correlation with the levels of heavy metals such as Zn and Pb.

2) Characteristics of Health Risks in Chinese Cities

Through a comprehensive review of a substantial body of literature, we found that urban environmental risks are transmitted to health risks through multiple pathways, exhibiting distinct characteristics such as pronounced carcinogenicity, the vulnerability of sensitive populations, and an expansion of impact dimensions.

Firstly, the carcinogenic risks associated with respiratory exposure have emerged as one of the most pressing health threats. Studies focusing on the exposure of occupational populations in Chinese cities to volatile organic compounds (VOCs) indicate that the lifetime cancer risk for working individuals significantly exceeds acceptable benchmarks. Specifically, the average lifetime cancer risk for women and men reaches 2.27×10^{-4} and 2.93×10^{-4}, respectively. The primary contributors to this risk include formaldehyde, 1,4-dichlorobenzene, benzene, and 1,3-butadiene, with approximately 70% of exposure risks occurring in indoor environments (Zhang, 2017). The chronic exposure risks of heavy metals via routes such as hand-to-mouth contact also cannot be overlooked. In Hangzhou, the non-carcinogenic risk of lead (Pb) in urban dust has exceeded safety thresholds for infants and young children, posing a potential threat to the health of urban children.

Secondly, the health vulnerability of sensitive populations is particularly pronounced in risk exposure, demonstrating distinctive characteristics of population differentiation. Research on microbial risks associated with recreational water activities reveals that men have higher exposure frequencies and durations during activities such as swimming and boating compared to women, resulting in infection risks of Cryptosporidium and Giardia of 1.0×10^{-2} and 8.8×10^{-3}, respectively (Li, 2022a); While the annual exposure frequency for individuals over 35 is higher than that of younger groups, the latter tend to have longer single exposure durations during high-intensity activities, resulting in a "frequency-duration" risk compensation effect. The Lancet report's urban-scale data reveals broader vulnerabilities, indicating that residents in regions such as South and Southwest China experience an annual sleep loss of up to 23 hours due to high temperatures, with deep sleep decreasing by approximately 20%. This chronic health impairment poses an additive risk for the elderly and those with chronic illnesses (Yang et al., 2025a).

Finally, the dimensions of health risk are expanding from physiological aspects to socio-economic factors. The loss of labor productivity related to high temperatures and direct losses from outdoor activities has reached unprecedented levels, increasing by 15% to 85% compared to the 1986 baseline. Additionally, the exposure of populations to the risk of infectious diarrhea caused by extreme rainfall and drought has doubled compared to 30 years ago, with drought exposure increasing by more than tenfold. Coincidentally, the spread of vector-borne diseases has further intensified the risk burden, with the climate suitability for dengue fever increasing by over 100% compared to 20 years ago. In 2024, the disease burden surged from an average of 25 cases per year in 2009 to over 870 cases, while the mosquito life cycle has formed a closed loop in over 200 cities, creating a persistent risk of transmission.

3) Approaches to Managing Urban Environmental Health Risks in China

According to the latest research, the governance of urban environmental health risks in China has evolved over more than sixty years, essentially establishing a three-stage evolutionary path that aligns with the stages of economic and social development. Each stage exhibits distinct governance logic and practical characteristics, as outlined below:

First is the "Pollute First, Manage Later" stage (1949-Early 1990s): During this stage, governance was centered around economic priorities, with environmental regulation characterized by a passive "post-hoc remedy" approach. In the early years of the founding of New China, the industrialization process primarily focused on extensive resource development, and environmental health policies were in their nascent stage. A systematic framework had not yet been established, and only temporary measures were taken in response to significant pollution incidents. The governance practices during this stage had limitations; industrial cities, while rapidly developing, failed to establish effective pollution prevention and control mechanisms. This led to the accumulation of issues such as direct discharge of pollutants, which sowed the seeds for future environmental health risks (Yang, 2023). Experience indicates that the absence of risk management during this stage resulted in irreversible health damage. For instance, in early industrialized cities of South China, soil contamination with heavy metals resulted in remediation costs exceeding ten times the previous economic benefits.

Second is the phase of simultaneous pollution and governance (mid-1990s to 2012): With the enactment of the Environmental Protection Law and other legislation, environmental health governance entered a transitional phase characterized by a dual focus on "prevention and remediation." The policy framework evolved from ambiguity to specificity. During this phase, the focus of governance shifted toward establishing standardized monitoring systems and targeted remediation mechanisms. Environmental regulations transitioned from broad oversight to precise monitoring; however, governance practices still exhibited structural deficiencies: On one hand, the issue of uneven regional governance is prominent, with approximately 50% of environmental health research concentrated in major cities, while smaller cities that face higher risks lack sufficient research support (Zhou, 2025); On the other hand, the focus of governance is excessively skewed towards the control of single pollutants, neglecting emerging risks such as wildfires that are rapidly increasing. The efficiency of governance is significantly impacted by administrative barriers, and the disparities in environmental governance performance across the three major river basins reflect issues of insufficient regional coordination (Xu et al., 2025).

Third is the phase of balanced attention to both symptoms and root causes (2012 to present): The construction of ecological civilization has been incorporated into the overall layout of "five-in-one," and environmental health governance has undergone a strategic upgrade from singular control to systemic management. The core characteristic of this phase is the integration of a "health-first" value orientation with a "multistakeholder co-governance" system. This is achieved through the three major battles for the protection of "blue skies, clear waters, and clean lands," resulting in a reduction of PM2.5 concentrations in cities at the prefecture level and above from 72 μg/m^3 in 2013 to 30 μg/m^3 in 2022, with the proportion of surface water quality meeting excellent standards rising to 84.9%. At the same time, there have been three significant breakthroughs in policy innovation: first, city-level targeted governance has replaced provincial-level average governance, with the introduction of annual action plans that clarify responsibilities and roles; Second, a cross-departmental coordination mechanism has been established, with the National Center for Disease Control and Prevention (CDC) and the Meteorological Administration jointly issuing health alerts. The recent high-temperature health warning issued by these agencies covers 588 million people, boosting response efficiency by 40% compared to pre-2012 levels; Third, the economic conversion of governance benefits has been achieved, with the benefit-cost ratio for ecological measures such as green roofs reaching 1.6 to 3.8, while the return on investment for early warning systems is even higher. The governance practices of this phase have established international referential value, providing a model of "government-led, technology-supported, and public participation" for developing countries.

4) Evolution of China's Environmental Health Risk Management Policies

Based on the core research and policy practices surrounding China's environmental health risk regulation, we believe that the evolution of China's environmental health risk management policies can be seen as a transition from a singular focus on pollution control to a more diversified system of governance; from broad, experience-based decision-making to precise, science-based regulation; and from localized emergency responses to comprehensive, sustainable governance. The characteristics of this evolution can be analyzed through three dimensions: regulatory indicators, regulatory perspectives, and regulatory methods.

The first dimension is regulatory indicators. China's environmental health risk regulation has undergone an upgrade from a focus on "single pollutants" to "multiple environmental factors" and finally to "health-related composite indicators. "Early regulatory indicators focused on the control of single pollutants. However, as demands deepened, the indicator system expanded to encompass the coordinated control of multiple environmental media. In recent years, indicators have further extended into the health-related dimension. For instance, the climate health risk indicators established by Cai et al. (2025a) directly associate with eight categories of health risks related to vector-borne diseases. This marks a transition of regulatory indicators from an "environmental quality-oriented" approach to a "health protection-oriented" approach. Additionally, the quantification of indicators has continued to improve, exemplified by the formula for accurately measuring the bioavailability of heavy metals through "*in vitro* physiological extraction amount/total amount × 100%," which provides a quantitative basis for regulatory decision-making.

The second dimension is regulatory perspectives. Currently, environmental health risk regulation is gradually breaking free from the limitations of a single field, evolving into a multidisciplinary, interdisciplinary perspective that fosters collaboration among multiple stakeholders. In the ecological dimension, some scholars focus on impermeable surface rates and categorize risk control intervals into three groups: <40%, 40% - 70%, and >70%. They develop a spatial governance framework based on ecosystem service functions (Yang et al., 2022); In the public health dimension, some scholars focus on indicators such as the coverage of health warnings among populations and the efficiency of warning responses, thereby strengthening health risk prevention and control within the context of emergency management (National Disease Control and Prevention Bureau, 2025); the institutional dimension, policy evolution can generally be divided into four stages: "emergence, foundation laying, deep adjustment, and strategic upgrade." This progression is analyzed through a sociological lens to elucidate the logic of institutional change (Hong et al., 2024). In the dimension of regional coordination, representative studies utilize the super-efficiency SBM-DEA model to assess environmental governance performance, focusing on the differences in governance efficiency among regions. In the dimension of global governance, the United Nations Climate Change Conference has proposed five assessment criteria for urban climate adaptation actions: scientific validity, relevance, economic feasibility, coordination, and sustainability. This initiative aims to promote the localization and adaptation of China's environmental health regulations within the global governance framework.

The third dimension is regulatory methods. The scientific advancement of regulatory approaches has gradually reduced reliance on empiricism in environmental health risk regulation, leading to an upgraded methodology chain of "qualitative categorization-quantitative calculation-model simulation." Early regulation primarily focused on qualitative classification, as illustrated by Hong et al. (2024), who defined four stages of policy evolution, emphasizing macro trend assessments. In the mid-stage, quantitative calculations were gradually introduced, such as the formula for measuring air quality improvement by the Blue Sky Defense Task Force, enhancing the precision of regulation (Chinese Academy of Engineering, 2020). In recent years, the application of complex models has become a significant breakthrough in regulatory methods. Some scholars have constructed a composite pollution risk index using the entropy weight-TOPSIS method, which incorporates "hazard factors × exposure × vulnerability" (Li et al., 2024). Additionally, research has utilized the super-efficiency SBM-DEA model to assess governance performance. These models not only achieve multi-factor coupling analysis but also effectively address uncertainty factors in regulation, providing scientific support for differentiated regulation.

In summary, China's environmental health risk regulation continues to adjust the relationship between "development and protection." It has evolved from a passive response to "pollution control" to proactive prevention through "synergy between environment and health," and further to "systematic governance of ecology, health, economy, and global cooperation." This evolution reflects a shift in environmental regulation from "instrumental rationality" to "value rationality," providing theoretical and practical references for the subsequent refinement and systematization of environmental health risk governance. The specific changes in detailed indicator dimensions can be referred to in **Table 1**:

Table 1. Evolution of environmental health risk management indicators in Chinese cities.

Author	Caliber	Perspective
Cai Wenjia, et al. (2025a)	The urban-level climate health risk assessment consists of 33 indicators, covering eight core risk categories, including high temperatures, diarrhea, and vector-borne diseases.	Precision governance prioritizing public health.
Yang Guishan, et al. (2022)	Using impermeable surface rates as the core indicator, the risk management zones are categorized into three intervals: <40%, 40% - 70%, and >70%.	Spatial governance of ecosystem services.
Hong Dayong, et al. (2024)	Four stages of policy evolution: emergence and groundwork, initial development, deepening and adjustment, strategic upgrade.	Institutional change
Zhang Yuanhang, et al. (2025b)	With PM2.5, surface water quality, and soil safety utilization rate as the core performance indicators.	Systematic governance of ecological civilization construction.
Li Jinjun, et al. (2024)	Compound Pollution Risk Index = Hazard Factor × Exposure Level × Vulnerability (Entropy Weight – TOPSIS Method)	Multi-factor Coupling of Sustainable Development
Du Zhengjian, et al. (2014)	Occupational VOCs Exposure Risk = Concentration × Inhalation Rate × Carcinogenic Potency Factor	Probabilistic Statistics of Risk Assessment
Guan Dongxing, et al. (2025)	Bioavailability of Heavy Metals = (*In Vitro* Physiological Extraction Amount/Total Amount) × 100%	Toxicology of Exposure Pathways

Continued

National Center for Disease Control and Prevention (2024)	Population Covered by High-Temperature Health Warnings, Warning Response Efficiency, and Reduction Rate of Medical Expenditures	Public Health Emergency Management
Xu Mengzhi, et al. (2024)	Environmental Governance Performance = Expected Output/(Unexpected Output + Input) (Super Efficiency SBM-DEA Model)	Evaluation of Regional Coordinated Efficiency
Li TianTian, et al. (2022)	Microbial Infection Risk = Exposure Frequency × Duration of Single Exposure × Pathogen Concentration	Exposure Science of Human Behavior
United Nations (2025)	Five Evaluation Criteria for Urban Climate Adaptation Actions: Scientific Basis, Targeted Approach, Economic Viability, Collaborative Efforts, and Sustainability.	Localization and Adaptation of Global Governance.
Yu Sijie et al. (2023)	Risk Driver Intensity = Contribution of Impervious Surface Expansion (45%) + Contribution of Population Growth (25%) + Contribution of GDP (30%).	Causal Analysis of the Urbanization Process.
Blue Sky Defense Assessment Group (2022)	Air Quality Improvement Rate = (Baseline Year PM2.5 Concentratio1n − Current Year Concentration)/Baseline Year Concentration × 100%.	Effect-Oriented Approach to Pollution Prevention and Control.

3. Implications and Characteristics of Industry Upgrading

1) Basic Implications and Theoretical Research on Industry Upgrading

The earliest research on industry upgrading in the West can be traced back to the work of William Petty in "Political Arithmetic," where he explored the relationship between economic development and changes in industrial structure.

Chinese scholars have developed a theory of industry upgrading that is distinctively characterized by China's unique context. In China, Qiu (1986) was the first to discuss industry upgrading in the context of industrial structure transformation in Guangdong; Subsequently, Cai et al. (2009) introduced the "Flying Geese Model" for major countries, which elucidates China's distinctive characteristics of regional leapfrogging in industrial evolution and the achievement of industrial gradient transfer within the country through differences in factor endowments; According to the principles of Marxist political economy, Wei (2018) proposed that the core of industrial upgrading is the enhancement of labor productivity. The process of industrial upgrading is a dynamic one, driven by the external pressures of competition in capitalism and the internal motivation for excessive profits, through which industrial capital continuously introduces new methods, models, and technologies to accumulate industrial development capabilities; Yuan et al. (2023) suggested that industrial upgrading is the manifest result of capital's pursuit of expansion and proliferation under the internal impetus of the contradictions between productive forces and production relations, as well as the external pressure from declining average profit rates. Its essence lies in the dynamic process of nurturing and accumulating the proliferative capacity of industrial capital. The Chinese government views industrial transformation and upgrading as a systematic adjustment made to adapt to macroeconomic conditions, technological trends, and market changes. This approach encompasses both upgrades within industries and the optimization of inter-industry structures. The key lies in promoting industrial development to achieve qualitative leaps, with the core focus shifting from factor-driven growth to innovation-driven progress. Essentially, it involves comprehensive enhancements in total factor productivity through transformations in dynamics, efficiency, and quality.

Overall, the mainstream perspective on industrial upgrading in the West is relatively micro-oriented, with a weakening of structuralism and a focus on the enterprise level. In contrast, China adopts a more macro perspective, maintaining a structuralist viewpoint while incorporating theories such as global value chains and Marx's theory of industrial upgrading, reflecting its unique characteristics (Tang, 2012; Yuan et al., 2023). Currently, the connotation of industrial upgrading is becoming increasingly rich, with deepening connections to areas such as green transformation, sustainable development, autonomous control of industrial chains, and industrial integration. As a result, industrial upgrading is evolving into a more complex and diverse concept that reflects the overall development level of the nation.

2) Research on Existing Mainstream Measurement Methods for Industrial Upgrading

Due to the varying developmental paths of different economies globally, the emphasis on industrial upgrading varies among countries, enterprises, and other entities, largely influenced by deep-seated differences in institutions and values. Furthermore, the rapid iteration of technology and the evolving connotation of industrial upgrading contribute to the uncertainty in evaluating and estimating industrial upgrading, resulting in the absence of a unified standard. The mainstream measurement systems for industrial upgrading are summarized in Table 2:

Table 2. Measurement methods and indicators for industrial upgrading.

Method	Representative Author	Measurement Method
Industrial Structure Hierarchy Coefficient Method	An et al. (2025)	The level of industrial upgrading is measured by multiplying the proportion of industrial output value by the summation of the industrial hierarchy.
Angle Method	Cheng et al. (2025) Li et al. (2025) Wu et al. (2024)	The level of industrial upgrading is measured from two perspectives: the rationalization of industrial upgrading and the advancement of industrial upgrading.
Function Equilibrium Method	Hu & Zhou (2025) Sun et al. (2025b)	By examining the utility function of consumption upgrading, the production function of industrial upgrading, and the equilibrium conditions of investment tendencies in the R & D sector, a comprehensive index is developed to reflect the transition from labor-intensive to technology-intensive industrial upgrading.
R & D Marketing Proportion Method	Xi et al. (2025)	Decompose the production value added to calculate the proportion of R & D and marketing in different industries relative to total output, using these proportions to estimate the level of industrial upgrading.
Output Value Ratio Method	Yang et al. (2024b)	Measure the level of industrial upgrading by the ratio of the value added of the tertiary industry to that of the secondary industry.

First, there is the method of industry structure hierarchy coefficient. This method measures the level of industrial upgrading by multiplying the proportion of industry output value by the sum of industry hierarchy levels. It effectively reflects changes in the overall structure of industries; however, it does not capture specific indicators such as upgrades within industries or technological advancements. Therefore, it is more suitable for overall analysis (An et al., 2025).

Second, there is the angular method. The angular method measures the level of industrial upgrading from two perspectives: the rationalization of industrial upgrading and the advancement of industrial upgrading. Since there is no unified standard for either the rationalization or advancement of industrial upgrading, the calculation methods are not consistent. For instance, methods such as the entropy weighting method or weighted summation based on indicators like the proportion of employed personnel may be used. Although the angular method can reflect industrial upgrading from two perspectives, its effectiveness and applicability still need to be determined based on the specific calculation methods due to the subjectivity involved in indicator selection (Wu et al., 2024; Cheng et al., 2025; Li et al., 2025).

Third, the function equilibrium method refers to the formulation of an industrial upgrading index that comprehensively reflects the transition from labor-intensive to technology-intensive industries by analyzing the utility function of consumption upgrading, the production function of industrial upgrading, and the equilibrium conditions of investment inclination in the research and development sector. This method can provide a comprehensive measurement of the overall state of industrial upgrading. However, due to the reliance on strict assumptions associated with various functions in model selection, the results tend to be more theoretical. The function equilibrium method may not necessarily capture the complexities of industrial upgrading related to production involving public goods and diverse demands (Hu et al., 2025; Sun et al., 2025b).

Due to the diverse connotations of industrial upgrading, the variety of explanations provided by different economic theories, and the complexities and challenges of data processing, there are many other commonly used measurement methods for industrial upgrading.

For example, focusing on key components facilitates data processing and analysis while effectively characterizing industrial upgrading, making it a common measurement approach. Taking the ratio of research and development (R & D) to marketing as an example, R & D represents high value-added segments, while marketing reflects the attractiveness of the industry. Therefore, by decomposing production value added to calculate the proportions of R & D and marketing in total output for different industries, one can estimate the level of industrial upgrading based on the size of these proportions (Xi et al., 2025).

Additionally, adjusting the details of existing methods to better reflect research needs is another common measurement approach. For instance, in the output comparison method, industrial upgrading is primarily characterized by changes in the total volume and proportion of the tertiary and secondary sectors. Therefore, the ratio of value added in the tertiary sector to that in the secondary sector can be used to measure changes in industrial structure, thus reflecting the level of industrial upgrading. This method is essentially a variation of the pre-existing industrial structure coefficient method (Yang et al., 2024b).

3) Factors Influencing Industrial Upgrading and Their Mechanisms of Action

Industrial upgrading is the result of the comprehensive interaction of various economic factors, stemming from the complex mechanisms of policies, technologies, markets, and other aspects. In summary, existing research categorizes the influencing factors of industrial upgrading into the following four main types:

Firstly, policy factors, which include various industrial support policies, related policy pilot programs, and market entry restrictions. In terms of mechanisms, government-directed support policies have the effect of improving market imperfections, reducing the costs associated with the survival of the fittest, and enhancing resource allocation due to screening biases. As industries progressively upgrade, the significance of screening biases becomes increasingly pronounced, leading to a shift in the effects of policies from predominantly positive to increasingly negative regarding industrial upgrading (Wu, 2023); Relevant policy pilot programs influence industrial upgrading through mechanisms such as resource allocation optimization, institutional dividend effects, and resource agglomeration effects. Additionally, the specific characteristics of these mechanisms vary due to differences in the policies implemented (Li et al., 2025; Liu, 2024; Yang et al., 2025b; Song et al., 2025); Market entry restrictions can both hinder industrial upgrading by distorting market allocation and facilitate structural upgrades by promoting regional technological innovation through a negative list system (Cai et al., 2025b); Government venture capital enhances the level of capital supply, enabling changes in urban regional driving structures, adjustments in the demand structure for urban products, and transformations in urban employment structures, thereby promoting social division of labor and facilitating industrial upgrading (Wang, 2024).

Secondly, technological factors encompass the degree of industrial digitalization and intelligence, as well as the capacity for technological innovation. Mechanistically, industrial digitalization can promote industrial upgrading through spillover effects and integration effects, optimizing factor allocation, and reshaping the value chain structure (Wang et al., 2025b; Xiong et al., 2025). Intelligentization promotes industrial upgrading by facilitating the relocation of industrial locations, necessitating technological transformation, upgrading the labor structure, optimizing resource allocation, and creating new business models, which in turn enhance international competitiveness and innovation levels (Liu, 2024; Liu et al., 2021; Peng, 2025); Digital trade directly facilitates industrial upgrading through the high mobility of data factors and changes in input methods, while also indirectly promoting industrial upgrading from four dimensions: technological innovation, transaction costs, consumer demand, and human capital (Tang &

Lan, 2024). Research innovation capability can foster a conducive research environment, enhance the quality of research outputs and their market application levels, increase productivity, and reshape product forms and competitive landscapes, thereby driving industrial upgrading (Cheng et al., 2025; Li, 2022b).

Thirdly, market factors encompass elements such as financial support, consumption levels, and market reforms. Mechanistically, finance drives industrial upgrading by directing capital allocation and optimizing structure through the aggregation of funds towards emerging industries, facilitating the flow of resources (Li et al., 2024). Demand-side dynamics drive industrial upgrading through consumption upgrading, impacting it via income elasticity mechanisms, resource allocation mechanisms, technological innovation mechanisms, and profit-oriented market mechanisms (Long et al., 2022; Sun et al., 2025a; Zhang et al., 2022); Market reforms can enhance market efficiency; for instance, the market-based allocation of resources promotes manufacturing upgrading by improving resource allocation efficiency and accelerating technological advancement (Yang, 2025); The market integration of urban agglomerations can facilitate broader division of labor, thereby promoting the advancement of industrial structure to a higher level (Chen et al., 2024).

Fourth, international factors include elements such as international markets and platforms for international cooperation. Trade frictions in international markets affect the entry ratio of technology-driven enterprises, thereby influencing industrial structure adjustments. Increased imports promote industrial upgrading through the optimization of consumption structures and the expansion of consumption scale. Furthermore, a broad export outlook incentivizes industries to enhance their advantages and improve production efficiency. The international market also provides targets for the relocation of various industrial segments, thereby leveraging the effects of open development and human capital (Wang, 2024; Liu et al., 2024). International cooperation platforms contribute to promoting industrial upgrading by harnessing the effects of open development to facilitate international trade, talent cultivation, and the siphoning effect of human capital. This helps diversify capital sources, integrate into the global market, and obtain technological and economic assistance (Pan et al., 2025; Lombardozzi, 2025).

4) The Journey of Industrial Upgrading in China

Since the reform and opening-up, China's industrial upgrading policies have continually adjusted in response to the characteristics of economic development stages, the dynamics of international competition, and national strategic needs. This process has undergone four key transformations, gradually shifting from "factor-driven scale expansion" to "innovation-driven emphasis on both safety and quality," thereby establishing a practical framework that aligns with industrial upgrading theories:

The first stage spans from 1978 to the early 1990s, marked as the period of enlightenment for outward-oriented industries centered around the "Three Imports and One Compensation" model. During this time, China aimed to "address factor shortages and integrate into the international division of labor" by leveraging low-cost labor and land resources to initiate foundational industrialization. The "Guangdong Provincial Economic and Trade Chronicle: Processing Trade Volume" indicates that the first processing trade enterprise in the country, the Guangdong Taiping Handbag Factory, successfully commenced operations in 1978. The "Three Imports and One Compensation" model—referring to "import processing, sample processing, assembly of imported components, and compensation trade"—was initially promoted in the Pearl River Delta, serving as a core mechanism for attracting foreign investment, technology, and managerial expertise. Simultaneously, the government enacted policies such as the "Regulations on Vigorously Developing Foreign Trade to Increase Foreign Exchange Income," which streamlined foreign investment approval processes, established special economic zones and coastal open cities, and reduced tariff barriers on processing trade. According to the "China Statistical Yearbook (1993)," these measures resulted in an increase in export volume from 13.66 billion in 1979 to 13.66 billion in 1979 to 84.94 billion in 1992, thereby laying the groundwork for the emergence of the "world factory." China's industrial system transitioned from a "shortage economy" to "basic supply"; however, the industry predominantly remained labor-intensive in nature, characterized by low technological content and added value, reflecting a pattern of extensive development.

The second stage spans from the mid-1990s to 2012, characterized as the structural optimization period of "transitioning from quantity to quality." In response to the "two fundamental transformations"—the shift from a planned economy to a market economy and from extensive growth to intensive growth—China aimed to advance its industry from "scale expansion" to "structural upgrading." In 1995, the 14th National Congress of the Communist Party of China proposed a strategy of "winning by quality," which facilitated an increase in the proportion of industrial manufactured goods in exports. As a result, the export share of high-tech products rose from 5% in 1992 to 17% by 2001. Following China's accession to the WTO in 2001, the country implemented the "Going Global" strategy to encourage enterprises to engage in global division of labor while introducing the "Guidelines for Industrial Structure Adjustment" to restrict the expansion of high-energy-consuming and high-polluting industries. Concurrently, China began to accelerate its technological research and development efforts by launching initiatives such as the "863 Program" outlined in the "National High-Tech R & D Program" and the "973 Program" specified in the "National Key Basic Research Development Plan." These programs aimed to support the development of key technologies and to establish a preliminary cooperative mechanism among industry, academia, and research institutions. This stage of development enabled China's manufacturing value-added to surpass that of the United States by 2010, establishing the country as the world's leading manufacturing power. The industrial structure shifted from "agriculture-dominated" to "industry-dominated," with the service sector's share rising from 32.9% in 1995 to 45.5% in 2012. However, reliance on imports for core technologies and high-end equipment persisted.

The third stage, spanning from 2012 to 2020, is characterized as the initiation of high-quality development focused on "supply-side reform and innovation-driven" growth. During this period, China successfully addressed the structural contradiction of "overcapacity versus insufficient effective supply" and promoted a transformation of the industry from being "factor-driven" to "innovation-driven." This phase implemented the strategy of "three transformations": transitioning from "Made in China" to "Created in China," from "Chinese speed" to "Chinese quality," and from "Chinese products" to "Chinese brands." During the process of supply-side structural reform, the "three reductions, one drop, and one supplementation" strategy proposed in 2015 focused on resolving the excess capacity in industries such as steel and coal, while also increasing support for "weak sectors" such as high-end equipment and chips. At the same time, China's innovation system has been comprehensively strengthened. According to data from the announcement by the Ministry of Finance and the State Taxation Administration on further improving the tax deduction policy for research and development expenses, China's "Made in China 2025" initiative focuses on ten key areas, including next-generation information technology, high-end equipment, and biomedicine. It promotes the establishment of pilot platforms for manufacturing and encourages over 150,000 large-scale industrial enterprises to engage in R & D activities, aiming to achieve more than 800 billion yuan in tax reductions from the enhanced deduction policy by 2024; In addition, the acceleration of the green transformation of industries has integrated ecological civilization construction into the overall layout of the "five-in-one" strategy. The "Blue Sky, Clear Water, Clean Land" defense battle has pressured high-pollution industries to upgrade, yielding significant results. This stage has led to a marked optimization of China's supply structure, with the added value of high-tech industries significantly increasing their share in large-scale industrial output, while the proportion of the tertiary sector has also noticeably risen.

The fourth phase, from 2020 to the present (the strategic upgrading period of "promoting development and security concurrently"), focuses on strengthening the resilience of industrial and supply chains in response to geopolitical conflicts, technological blockades, and the risks of supply chain disruptions, while building on the foundation of high-quality development. The Central Economic Work Conference has, for the first time, proposed that "industrial policy should promote development and security concurrently," focusing on critical areas such as semiconductors and high-end chips that are pivotal for national interests. It aims to promote the domestic substitution of key core technologies and accelerate the construction of a global industrial security system. This includes implementing an "asymmetric globalization" strategy to establish a division of labor that prioritizes China's strengths in areas such as new energy and the digital economy, while also mitigating "decoupling" risks through regional trade agreements like the RCEP; China is also simultaneously promoting a combination of inclusive and functional policies, reducing selective industry subsidies, implementing broad-based R & D incentives, and strengthening fair competition reviews to avoid "resource misallocation". The Ministry of Industry and Information Technology announced that these measures will enable China's total value of technology contract transactions to surpass 6.8 trillion yuan in 2024, successfully achieving the goals outlined in the 14th Five-Year Plan ahead of schedule. This achievement will significantly enhance the domestic substitution rate in key sectors and strengthen the resilience of the industrial chain. Moreover, the "2024 Digital Transformation Development Report for Manufacturing in the Yangtze River Delta" indicates that, in the face of challenges such as the dengue fever outbreak and extreme heat risks, the manufacturing sector in the Yangtze River Delta will reduce production interruption time by over 30% through digital transformation initiatives.

4. The Impact of Urban Environmental Health Risk Management on Industrial Upgrading

1) The Direct Impact of Urban Environmental Health Risk Management on Industrial Upgrading

Urban environmental health risks, arising from the intersection of urbanization and global environmental changes, have evolved from a singular public health issue into a key variable influencing the foundational logic of industrial development. This encompasses a diverse range of concerns, including climate-related health threats, environmental pollution risks, and occupational health hazards. Industrial upgrading is driven primarily by technological innovation, manifesting as an evolutionary process characterized by the advancement of industrial structure, the greening of production methods, and the enhancement of supply chain resilience. In 2024, unprecedented global meteorological records and the restructuring of supply chains following the COVID-19 pandemic have propelled academia to deepen the exploration of the interactive relationship between urban health risks and industrial upgrading. In 2025, The Lancet Countdown on Health and Climate Change's China Report first refined the study of climate health risks to the urban level, revealing their profound penetration into economic systems. Additionally, numerous studies have highlighted the role of health risks in reshaping industrial layouts from the perspective of supply chain security.

Overall, the direct impact of urban environmental health risk management on industrial upgrading can be categorized into two representative viewpoints.

Firstly, urban environmental health risk management can promote urban industrial upgrading. Some studies have found that urban environmental health risk management compels breakthroughs in green, low-carbon, and health technology industries: climate-related health risks have become a core catalyst for green technology innovation. In 2024, China's potential productivity loss related to heat is projected to reach $282.6 billion, directly driving the accelerated upgrade of the renewable energy industry—solar power generation has seen a year-on-year increase of 28.7%, and the number of jobs in renewable energy has risen to 7.39 million, marking a 34% increase from the previous year (Zhang et al., 2025a). At the same time, research in the United States has also confirmed that the transition to zero-emission thermal technologies in the industrial sector can not only reduce labor mortality risks but also accelerate the growth of the clean equipment industry, creating a substantial number of new job opportunities (American Lung Association, 2025). In addition, the demand for environmental health risk management is driving the iteration of environmental protection technologies. Urban water pollution has led to a 37% increase in related global morbidity rates, compelling the rapid commercialization of water treatment technologies such as membrane separation and advanced oxidation. In 2024, the global environmental protection equipment market is expected to expand rapidly, with a growing share of water purification equipment, while the health technology sector is experiencing cross-sector integration in response to risk management needs. In 2024, the average sleep loss per person in China exceeded 20 hours, a health risk that has spurred an explosion in the sleep monitoring device industry. Companies like Huawei and Xiaomi have developed sleep monitoring bracelets equipped with technologies such as temperature sensing and environmental noise reduction. As a result, the market share of related products has surpassed 60%; In response to the UV exposure risks faced by workers in the photovoltaic industry, some Indian companies have introduced wearable ultraviolet monitoring devices and smart shading systems, resulting in a 27% increase in the added value of related equipment manufacturing (Anjanappa, 2025).

Secondly, urban environmental health risk management is driving the reconstruction of industrial space and the enhancement of supply chain resilience. Current studies indicate that the spatial disparities in urban health risks are promoting the optimization of industrial distribution. For instance, in China, the top five cities with the highest heatwave mortality risks account for 14.7% of the nation's total deaths. Additionally, underdeveloped southern cities like Qinzhou and Beihai have experienced heat-related GDP losses exceeding 4.9%. This differentiation in risk is prompting labor-intensive industries to relocate to regions with stronger climate adaptability, while simultaneously driving high-value-added industries to cluster in urban agglomerations with robust health risk governance capabilities (Cai et al., 2025a). At the same time, health risk management within the supply chain is driving digital transformation. Amid the global restructuring of industrial chains, health risks that restrict personnel movement are compelling companies to accelerate their digital upgrades. For instance, the Yangtze River Delta manufacturing cluster has introduced AI-driven remote quality inspection systems, which not only reduce production downtime but also enhance revenues from related digital services (Wu et al., 2025). Moreover, in response to the mental health risks and efficiency losses associated with remote work, the market for employee status monitoring and collaborative management software has exceeded 30 billion yuan. This trend is driving the verticalization and intelligent upgrade of the software services industry.

Lastly, urban environmental health risk management promotes the spillover effects of health investment industries. Specifically, public health investment significantly drives the upgrading of the service industry. The increasing aging population accelerates the growth of public health investment, resulting in a rise in the value added of related industries such as elderly care and health. Notably, the smart elderly care equipment industry has experienced particularly remarkable growth due to policy subsidies. Private health investment drives the extension of the consumption industry's value chain, significantly enhancing the spillover effects on the tertiary sector. Notably, sectors such as health food and sports equipment benefit the most (Chen et al., 2022).

Secondly, urban environmental health risk management may hinder urban industrial upgrading. Firstly, it can impact the stability of the labor market and production efficiency. A typical manifestation is that occupational health risks lead to a decline in the quality of labor supply. Research indicates that in 2024, the frequency of compounded heatwave exposures in China will increase by 197.9%. Under extreme high temperatures, the safe threshold for outdoor work is an average of only 2.52 hours per day, leading to a rising absenteeism rate in the manufacturing sector of 18%. In particular, the construction industry suffers a productivity loss of up to 15% due to heatstroke. A study on the renewable energy industry in India similarly confirms that 84% of solar workers lack safety training, and risks such as UV exposure contribute to an annual absenteeism rate of 22%, hindering the technological advancement of the photovoltaic industry (Anjanappa, 2025). Secondly, the discontinuity in the supply of skilled talent obstructs the upgrade of technology-intensive industries. Data indicates that by 2024, the talent gap in China's artificial intelligence sector will expand to 4 million, significantly prolonging the research and development cycles of core technologies such as autonomous driving and industrial software (Sawaya et al., 2023). Moreover, in the aftermath of the COVID-19 pandemic, restrictions on international talent mobility have not been fully lifted, leading to extended recruitment cycles for high-end engineers in the semiconductor industry and delays in breakthroughs for process technologies below 7 nm (World Economic Forum, 2025). Finally, changes in the labor structure intensify the pressure for industry upgrades. Health investments driven by an aging population have increased by 3.2%, resulting in an 8.7% decline in the proportion of young laborers in manufacturing (Wang et al., 2025a). The demand for the "machine-for-man" upgrade in labor-intensive industries is urgent; however, small and medium-sized enterprises struggle to adapt quickly due to funding constraints. This funding gap has led to a 2 - 3-year lag in the intelligent transformation of traditional industries.

Secondly, the management of urban environmental health risks has triggered a crowding-out effect of health investments on the real economy. Particularly in the field of public health investment, the crowding-out effect on funding for the upgrading of foundational industries is evident. At the domestic level in China, the aging population drives an increase in public health investment, which further amplifies the suppressive effect on the economic growth of foundational industries. At the same time, rising health-related costs weaken industrial competitiveness. A study focusing on the United States reveals that the medical costs associated with air pollution from traditional industrial combustion technologies increase the average operational costs for businesses. In particular, the steel and chemical industries experience a decline in their international market share due to environmental fines and health compensation expenditures (American Lung Association, 2025).

Again, urban environmental health risk management leads to disruptions in the industrial chain and chaotic spatial arrangements. Primarily, supply chain interruptions triggered by health risks constrain collaborative upgrading. For instance, the outbreak of dengue fever in multiple regions worldwide in 2024 severely impacted labor-intensive industries, particularly in Brazil's manufacturing sector. The disease resulted in productivity losses of up to 15.1 billion reais, healthcare costs reaching 5.2 billion reais, and could potentially lead to the loss of approximately 215,000 jobs. In China, pollution-related health risks further constrain the optimization of industrial space. A study focused on the country's aging industrial cities indicates that the high costs associated with land pollution remediation often make it challenging to site high-end manufacturing projects. This, in turn, hampers the effectiveness of policies aimed at promoting industrial upgrading in designated areas (Li et al., 2019).

2) The Mechanisms through which Urban Environmental Health Risk Management Affects Industrial Upgrading

From a mechanistic perspective, urban environmental health risk management primarily influences industrial upgrading through several mechanisms: the environmental entry threshold mechanism, the bias effect of technological advancement, the diffusion effect of technological progress, the industrial policy mechanism, and the industrial innovation mechanism. Depending on the specific implementation methods and targets, the realization of these mechanisms is subject to threshold effects and spatial spillover effects. Additionally, the effectiveness of certain mechanisms is constrained by factors such as comparative advantage and the resource curse, which can, in turn, produce counter-effects on urban environmental health risk management.

Firstly, the environmental entry threshold mechanism. The environmental entry threshold may lead to compliance cost effects, where the comparative advantages gained do not necessarily offset the increased compliance costs, resulting in a less pronounced incentive for industrial upgrading (Wilcoxen & Jorgenson, 1990). Under certain conditions, it may also give rise to a high-pollution refuge effect, which is detrimental to industrial upgrading. This phenomenon is particularly evident in the context of industrial policies that prioritize economic development, stringent emission reduction targets, and a lack of trading market conditions (Tang et al., 2016). On the other hand, strict yet reasonable environmental entry thresholds can enhance the screening effect influenced by industrial policies and the structure of fiscal expenditures, which tends to strengthen with increasing regional development levels. This mechanism can hinder the entry of high-pollution enterprises and favor high-tech, low-pollution firms, allowing them to gain first-mover advantages in the market and thereby promote industrial upgrading (Huang et al., 2024).

Secondly, the mechanism of technological advancement. The mechanism of technological advancement includes the incentives for technological progress, the bias effects of technological advancement, and the diffusion effects of technological progress. The incentive for technological advancement refers to the fact that under a well-designed and effective urban environmental health risk management system, urban environmental health risk management can stimulate technological progress, thereby driving industrial upgrading. Within industries, firms will actively improve their pollution control technology levels to meet management objectives, while across industries, the incentive mechanisms will strengthen the disparities in technological levels, subsequently promoting industrial structural upgrading and facilitating the realization of urban environmental health risk management (Xu et al., 2025). The bias effect of technological advancement refers to the capacity of moderate urban environmental health risk management to adjust and rationalize the direction of technological progress. This is achieved by altering the capital investment structure and employment structure, which in turn adjusts resource allocation and industrial structure, thereby promoting industrial upgrading (Wang et al., 2022). The diffusion effect of technological advancement refers to the facilitation of comparative advantage formation through international urban environmental health risk management, which encourages the global diffusion of environmentally friendly technologies (Costantini & Crespi, 2008).

Thirdly, there is the mechanism of industrial policy. The mechanism of industrial policy includes regulatory incentive and constraint mechanisms, policy guidance mechanisms, market incentive mechanisms, and their interplay with other mechanisms. The regulatory incentive and constraint mechanism refers to the use of stringent urban environmental health risk management as external pressure, which can encourage enterprises to overcome internal inertia, improve productivity, and subsequently promote industrial upgrading (Ambec & Barla, 2002). Moreover, effective industrial policies serve as a means and vehicle for the implementation of other mechanisms and can synergize with various industrial mechanisms. For example, environmental protection taxes inherently establish an invisible barrier to environmental access, enhance incentives for technological advancement, and also play a role in sending green signals and creating a favorable industrial environment (Cao et al., 2025). Finally, the implementation of environmental regulations exhibits a lagging effect, which means that long-term industrial policies are more effective than short-term policies in encouraging enterprises to overcome immediate costs and engage in innovation, thereby facilitating industrial upgrading (Zhang, 2017).

Fourth is the mechanism of industrial innovation. The mechanism of industrial innovation includes technology-driven mechanisms, as well as mechanisms for industrial creation. The Porter Effect initially highlighted the role of industrial innovation mechanisms in managing urban environmental health risks. It suggested that establishing a well-regulated urban environmental health risk management framework can incentivize enterprises to innovate, thereby offsetting compliance costs, enhancing comparative industrial advantages, and promoting technological upgrades (Porter & Linde, 1995). The technology-driven effect refers to the ability of urban environmental health risk management to encourage industries to actively adopt new technologies, leading to the formation of new industries and business models, and ultimately facilitating industrial upgrading. For instance, urban environmental health risk management can coordinate and promote industrial digitization, fostering the collaborative development of new digital industries and achieving industrial advancement (Yang et al., 2024a). The industrial creation mechanism refers to the ability of urban environmental health risk management to generate emerging industries that align with its objectives, such as the renewable energy sector, the biodegradable materials industry, and green financial services. These emerging industries not only meet the demands of urban environmental health risk management but also represent an upgrade of traditional sectors. By supporting the development of these new industries, urban environmental health risk management facilitates industrial upgrading (Xu et al., 2023).

However, under different policy contexts, the above mechanisms do not operate in isolation. Instead, they form dynamic interactions through "strengthened layering" or "offsetting constraints." The interaction effects are directly influenced by the intensity of the policies, their implementation timelines, and the combinations employed: Firstly, in situations with stringent regulations, multiple mechanisms can reinforce each other positively—particularly when "high-intensity entry requirements + strong innovation incentives" are at the core. The filtering effect of strict entry thresholds compels companies to intensify research and development in environmental protection technologies, while subsidies for R & D in industrial policies further reduce innovation costs, thereby enhancing the effects of technological advancement. New business models generated by technological breakthroughs expand their application through market incentives like carbon trading, promoting technological iteration and raising entry barriers, thereby reinforcing the filtering effect. A prime example of this is the "Blue Sky Defense War," which limits the entry of high-pollution enterprises and subsidizes the research and development of green technologies. This initiative drives technological breakthroughs in the renewable energy sector and fosters the cultivation of emerging business models, creating a positive feedback loop (Xu et al., 2022); Secondly, in situations with relaxed regulations, the mechanisms may cancel each other out—particularly when policies exhibit characteristics of "low entry barriers + weak guidance," leading to a mutual weakening of their effects. Low entry costs diminish the pressure on companies to upgrade technology, weakening the incentive for technological advancement. The retention of high-pollution enterprises may also crowd out resources meant for emerging industries. Moreover, a lack of targeted industrial subsidies may inadvertently be directed toward inefficient companies, failing to connect technological progress with industrial innovation, resulting in "policy inertia" and ultimately causing industrial upgrades to stagnate (Wang, 2022); Next, the distinction between short-term and long-term policies focuses on the temporal dimension of mechanism transformation—under stringent regulations in the short term, companies are required to invest substantial funds to meet compliance standards, which may encroach upon research and development resources. This, in turn, can offset technological progress and industrial innovation, and may even lead to industrial relocation. In the context of long-term comprehensive regulation, the sustained implementation of industrial policies leads to visible improvements in technological progress. Companies are able to reduce compliance costs through innovation, while emerging industries fill the gaps left by traditional sectors. Consequently, the entry barriers shift from being "restrictive" to "guiding," fostering a long-term collaborative synergy; Finally, the effects of single versus combined policies show significant differences—relying solely on a single policy can lead to drawbacks. For instance, depending only on entry barriers may trigger a "pollution refuge effect," while relying solely on industrial subsidies could result in "policy arbitrage." In contrast, the combination of "entry barriers + technological subsidies + innovation incentives + market mechanisms" effectively aligns with the demands of the mechanisms through differentiated entry standards, targeted technological support, and the cultivation of new business models. This approach avoids the limitations and resource misallocation associated with single policies and amplifies the effects of upgrading (Zhan, 2024).

5. Conclusion and Outlook

Overall, the governance of urban environmental health risks in China has undergone a historic transformation from passive response to proactive prevention and control, and is currently in a strategic upgrade phase that balances both symptoms and root causes. The current complexity and spatial heterogeneity of environmental risks, along with the differentiation of health risks across populations and the expansion of dimensions, necessitate a departure from the traditional "single control" governance model. Future research should focus on three main directions: first, strengthening empirical studies in small and medium-sized cities as well as high-risk areas to address the current spatial imbalance; second, developing multi-factor coupled risk assessment models that include blind spots such as mental health; and third, deepening the quantitative analysis of governance effectiveness to enhance policy tools that promote "health-economy" synergistic development. Further optimization of environmental regulations requires strengthening the dialogue between scientific rationality and social rationality. Through precise governance at the urban level and collaborative mechanisms across regions, the dual goals of improving environmental quality and enhancing health and well-being can be achieved.

Secondly, in the field of industrial upgrading research, the academic community has undergone long-term development, resulting in a theoretical framework, measurement methods, and impact mechanisms that reflect differences between Eastern and Western perspectives as well as temporal characteristics. However, further deepening and expansion of this research is still needed. In terms of theoretical connotations, Western perspectives tend to adopt a microenterprise view, while China focuses on a meso-macro structuralist approach, integrating multiple theories to form a distinctive system. As a result, the concept of industrial upgrading has become richer and has evolved into a complex, multifaceted notion. The diversity of measurement methods characterizes the level of industrial upgrading from different dimensions. However, due to variations in connotations, theoretical foundations, and the complexity of data, a unified standard has not yet been established. Regarding influencing factors, industrial upgrading is shaped by the combined effects of four key elements: policy, technology, market, and international dynamics. Each factor influences development through its unique mechanisms. Current research still has gaps: the standards for measurement methods are not unified; there is insufficient study on the interaction mechanisms of multiple factors; and research on the integration of new topics in the new era needs to be strengthened. In the future, a comprehensive multi-dimensional measurement system can be enhanced, deepening the analysis of interaction mechanisms among factors. By integrating Chinese practices to explore local industrial upgrading pathways, this will provide theoretical support and practical guidance for high-quality industrial development.

Next, in the relevant research on the impact of urban environmental health risk management on industrial upgrading, a comprehensive review reveals that the direct effects of urban environmental health risks on industrial upgrading exhibit a complex pattern characterized by "pressure-response-differentiation." Although existing research has established an analytical framework of "risk types-influence mechanisms-industry responses," there are still significant gaps: first, there is inadequate study on the mechanisms through which new technology risks affect industrial upgrading; second, there is a lack of systematic exploration of distinctive pathways for responding to health risks in developing countries in relation to industrial upgrading; and third, the interactive effects of health risks with multiple variables such as digitization and aging require further investigation. In the future, based on the "risk source-vulnerability-reduction capacity" theory, and by integrating city-level microdata with cross-country comparative studies, we can further elucidate the dynamic evolution of the relationship between urban environmental health risks and industrial upgrading. In terms of influence mechanisms, it is important to recognize that the impact of urban environmental health risk management on industrial upgrading generally exhibits threshold effects and spatial spillover effects (Wang, 2022). Additionally, it should take into account the constraints posed by urban economic or geographical conditions and resource endowments (Lu et al., 2020).

At the same time, it is apparent that many developing countries remain in a passive phase of "pollute first, control later." This often stems from a lack of systematic policy frameworks, resulting in environmental regulations that are merely formal and unable to effectively balance the dual demands of economic growth and health protection. Furthermore, when faced with complex pollution and spatial heterogeneity risks, these countries frequently encounter governance inefficiencies due to insufficient technological reserves and a lack of interdepartmental collaboration. Some countries have attempted to introduce environmental regulatory policies; however, they are often constrained by funding gaps and technological barriers, making it challenging to promote the green transformation of traditional industries. In some cases, inadequate regulatory intensity has even led to industrial migration or slowed economic growth. China's key insight lies in the establishment of a dynamic system that integrates "policy evolution and development stage adaptation," "multifaceted governance and precise regulation," and "health-oriented approaches and industrial upgrading coordination": Firstly, through a gradual governance approach of "pollute first, control later—manage pollution while it occurs—address both symptoms and root causes," China avoids the economic shocks associated with aggressive regulations while progressively reinforcing environmental health standards. This provides developing countries with a "phased and stepped" governance model; Secondly, a collaborative mechanism of "government leadership + corporate response + public participation" has been established to overcome the limitations of single-entity governance. This approach offers a practical pathway to address the issue of fragmented governance in developing countries; Thirdly, by prioritizing "health," regulatory indicators are upgraded from "single pollution control" to "health-related composite indicators." Additionally, mechanisms such as technological innovation incentives and coordinated industrial policies are employed to transform environmental health risks into drivers for industrial upgrading, fostering the development of emerging industries like green energy and health technology. This provides developing countries with new ideas for overcoming the dilemma of the opposition between environmental protection and economic growth. Moreover, China's practices in balancing governance resources between small and medium-sized cities and large cities, as well as in addressing the transformation of traditional industries alongside the cultivation of emerging industries, provide important references for other developing countries facing issues such as regional development imbalances and singular industrial structures. This highlights the potential for developing countries to achieve coordinated development of "environment-health-economy" through independent exploration.

In summary, we can distill the following direct political policy insights: First, we can establish a "risk zoning-targeted policy" mechanism that addresses the composite and spatial heterogeneity of urban environmental risks. This involves prioritizing the deployment of ecological infrastructure in high-risk areas, such as those affected by high-temperature pollution, and implementing differentiated management measures across functional zones. Additionally, by utilizing fiscal transfer payments and technical assistance, we can enhance the risk monitoring system for small and medium-sized cities and address any governance gaps; Second, we should promote the establishment of a "health-oriented-industry compatibility" policy toolbox. This includes enforcing strict access requirements for high-pollution industries while supporting emerging sectors such as green energy and health technology. We must optimize the spatial layout of industries, guiding labor-intensive industries to relocate to lower-risk areas and facilitating the clustering of high value-added industries. Additionally, we should drive the digitalization of the industrial chain and establish a health risk emergency mechanism to mitigate external shocks; Third, China needs to deepen the "government-led + corporate response + public participation" model by improving regulatory standards and incorporating health prevention and control into urban planning. It is essential to strengthen corporate accountability and encourage public engagement. Furthermore, we should establish a multi-departmental data-sharing and early warning coordination mechanism to promote inter-regional collaboration among watersheds and urban agglomerations, thereby addressing the issue of uneven governance; Finally, the government can introduce relevant policies to transition environmental health regulation toward "health-related composite indicators," incorporating metrics such as heat warning coverage into performance assessments. It is crucial to balance public health investments with those aimed at industrial upgrading, while increasing public funding in areas like elder care health and smart monitoring. Additionally, by leveraging green finance and carbon trading, we can encourage social capital to support environmental research and development as well as the transformation of traditional industries, thereby achieving collaborative development among the environment, health, and economy.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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