sustainability

MDPI

Article

How Does Green-Infrastructure Investment Empower Urban Sustainable Development?—Mechanisms and Empirical Tests

Shang Chen [1,†], Ziyi Wang [2,†], Danica Du [1] and Qiang Kong [3,*]

[1] School of Economics, Shandong Normal University, Jinan 250300, China; 13156163463@163.com (S.C.); 202227230412@stu.sdnu.edu.cn (D.D.)
[2] School of Business, Shandong Normal University, Jinan 250300, China; 202222430105@stu.sdnu.edu.cn
[3] School of Geography and Environment, Shandong Normal University, Jinan 250014, China
* Correspondence: kongqiang0531@hotmail.com
† These authors contributed equally to this work.

Abstract

Amidst the intensifying impacts of global economic turbulence and external instabilities, the urgency to enhance urban sustainable development capabilities has become increasingly pronounced. Urban green-infrastructure investment, as a pivotal investment direction, plays a significant role in strengthening urban sustainable development capabilities. Based on panel data from 281 prefecture-level cities in China from 2010 to 2022, this study employs an empirical model to thoroughly investigate the impact of urban green-infrastructure investment on urban sustainable development and its underlying mechanisms. The research findings indicate the following: ① Urban green-infrastructure investment significantly promotes the enhancement of urban sustainable development levels, a conclusion that remains robust after undergoing robustness tests. ② The mechanism tests reveal that the enhancement of industrial chain resilience, ecological environment resilience, and talent agglomeration are crucial pathways through which urban green-infrastructure investment drives sustainable urban economic development. ③ Heterogeneity analysis finds that cities in the central and western regions, resource-based cities, cities with lower levels of urbanization, and cities with higher degrees of openness are more sensitive to the sustainable development-enhancing effects of green-infrastructure investment. ④ Spatial effect tests show that urban green-infrastructure investment has a positive spatial spillover effect on enhancing urban sustainable development levels. Based on these findings, it is recommended that cities increase investment in green infrastructure, optimize investment structures, promote the enhancement of industrial chain and ecological environment resilience, strengthen talent agglomeration effects, and leverage regional comparative advantages to invest in green infrastructure in a location-specific manner. This study not only validates the positive impact of urban green-infrastructure investment on urban sustainable development but also provides multi-perspective insights and references for analyzing the effects of urban green-infrastructure investment, offering policy support for achieving urban sustainable development.

Keywords: green-infrastructure investment; urban sustainable development; industrial chain resilience; ecological environment resilience; talent agglomeration effect

check for updates

Academic Editor: Brian Deal

Received: 14 May 2025
Revised: 13 June 2025
Accepted: 17 June 2025
Published: 23 June 2025

Citation: Chen, S.; Wang, Z.; Du, D.; Kong, Q. How Does Green-Infrastructure Investment Empower Urban Sustainable Development?—Mechanisms and Empirical Tests. *Sustainability* **2025**, *17*, 5751. https://doi.org/10.3390/su17135751

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In recent years, the impact of global ecological degradation and external economic environments on the global economy has intensified, posing unprecedented challenges

to economic activities worldwide [1]. As the world's largest developing country and a major trading nation deeply integrated into the global market, China has been significantly affected by environmental deterioration and external economic shocks. Data shows that in 2024, China's real GDP grew by 4.6% year-on-year in the third quarter, slowing by 0.1 percentage points compared to the second quarter. In the first quarter of 2025, GDP increased by 5.4% year-on-year, a further decline from the same period in 2024. Under the persistent influence of weak demand, China's total retail sales of consumer goods grew by only 3.5% in 2024, far below the average of 10.5% from 2014 to 2019. Meanwhile, the pressure of environmental decline on economic sustainability has become increasingly evident [2]. In 2024, China experienced frequent exceedances of air PM2.5 concentration standards, and ozone pollution worsened, with some regions reporting ozone exceedance days accounting for over 30% of the total. Water pollution pressures also increased, with significant exceedances of indicators such as ammonia nitrogen and total phosphorus in some major rivers. Under the combined effects of internal and external factors, China's stable and positive economic development faces significant disruptions and threats. Therefore, exploring ways to enhance urban economic sustainability, boost the anti-interference capabilities of economic systems, and increase system resilience holds great contemporary significance. The level of urban economic sustainability can be measured by economic resilience, which refers to the ability of an economic system to quickly recover to its pre-shock state, or even achieve better development, after suffering external shocks such as natural disasters or economic crises, and to adapt to and withstand similar future shocks during the recovery process [3]. It is an important indicator of the stability and adaptability of an economic system, effectively reflecting its stress resistance and recovery capabilities in the face of uncertainties.

Cities, as key carriers of national economies, are characterized by highly concentrated economic activities and massive resource consumption. They face multiple risks, including natural disasters, economic fluctuations, and social unrest [4], and are the concentrated embodiment of environmental and economic pressures. They are also the direct units facing ecological degradation, economic turbulence, and the rise of trade protectionism. Changes in the external environment can not only directly impact urban infrastructure, residents' lives, and economic activities but also trigger chain reactions that affect the operation and development of the entire urban economy [5]. Against this backdrop, researching ways to enhance urban economic sustainability is not only an urgent need to address current environmental challenges but also an inevitable choice for achieving sustainable urban economic development. Enhancing urban economic sustainability is also of great significance to national development as a whole. It has become an urgent need and an important focus for China and other countries worldwide to cope with internal and external environmental changes, achieve high-quality economic development, and promote global economic stability [6]. With efforts from all sides, China has continuously deepened its work on enhancing economic resilience and achieved good results. From October to December 2024, China's manufacturing Purchasing Managers' Index (PMI) remained above the critical point for three consecutive months, with market expectations continuing to improve. In the first quarter of 2025, despite the impact of tariff disputes, China's total import and export volume of goods trade still achieved a year-on-year growth of 1.3%, with exports increasing by 6.9%, further demonstrating the strong resilience of China's foreign trade. In the future, with the further implementation of relevant policies worldwide and the recovery of market confidence, the economic sustainability of cities in China and around the world will inevitably continue to strengthen.

Green-infrastructure investment attempts to integrate green concepts into infrastructure construction, covering areas such as renewable energy facilities, green transportation

systems, ecological restoration projects, and water resource management [7]. It is primarily manifested in improving the urban ecological environment quality and resource utilization efficiency. Its core lies in combining environmental protection with economic development, meeting urban development needs in a sustainable manner, and continuously reducing dependence on natural resources and environmental degradation. Green-infrastructure investment is often based on environmental impact assessments, aiming to identify projects that significantly promote green economic sustainability. In practice, constructing renewable energy generation facilities can reduce urban dependence on traditional fossil fuels, lower carbon emissions, and enhance the stability and security of the energy supply [8]. Developing green transportation systems can alleviate urban traffic congestion, reduce air pollution, and improve residents' travel efficiency [9]. Implementing ecological restoration projects can improve the urban ecological environment and enhance urban livability. Therefore, increasing urban green-infrastructure investment not only helps improve the urban ecological environment but also creates new opportunities and momentum for urban economic development by optimizing resource allocation and improving technical efficiency. This, in turn, significantly enhances urban economic sustainability. Currently, China and other countries worldwide are actively promoting the development of green-infrastructure investment and have achieved phased results [10]. In 2023, the global green economy investment scale exceeded USD 1.7 trillion, setting a new historical record. China, the United States, and the European Union, the three major economic blocs, contributed 75% of the global green investment. According to the International Energy Agency, global investment in solar and wind energy maintained a growth rate of over 20% for the third consecutive year in 2024. The construction of green and intelligent infrastructure, such as new energy vehicles and green smart transportation, has injected strong momentum into the continuous high-speed development of the world economy [11,12].

However, current research on the relationship between green-infrastructure investment and sustainable urban economic development remains relatively insufficient. On the one hand, although some studies have acknowledged the existence of a relationship between green-infrastructure investment and sustainable urban economic development [13], they have failed to employ systematic empirical research to verify its actual impact on urban economic sustainability. On the other hand, while the studies by Herath [14] and Gong et al. [15] theoretically agree that green-infrastructure investment has a positive effect on sustainable urban economic development, they do not elaborate on the specific pathways and extent of this impact. Moreover, cities vary in terms of economic development levels, industrial structures, and resource endowments, and these differences may affect the impact of green-infrastructure investment on sustainable urban economic development. Therefore, an in-depth exploration of how green-infrastructure investment can enhance urban economic resilience is not only theoretically significant but also provides practical guidance for formulating policies on sustainable urban economic development. This paper aims to systematically analyze the mechanisms through which green-infrastructure investment affects sustainable urban economic development. Using panel data from 281 Chinese cities over the period 2010–2022, we empirically test its impact. We attempt to explore the potential pathways through which green-infrastructure investment can enhance urban economic sustainability from the perspectives of industrial chain resilience, ecological resilience, and talent agglomeration. We also pay particular attention to its spatial spillover effects and the differences in its impact on cities with different locations and development statuses. We hope that this study can effectively address the current research gaps in this area and provide useful references and insights for cities to cope with environmental challenges and enhance their economic sustainability. Ultimately, we aim to promote the green and sustainable development of cities worldwide.

2. Literature Review

To date, both domestic and international scholars have conducted extensive research on green-infrastructure investment and sustainable urban economic development capabilities, focusing primarily on the following three dimensions.

2.1. The Meaning, Motivation, Impact, and Mechanism of Urban Green-Infrastructure Investment

The concept of "green infrastructure" originated in architecture and specifically referred to the integration of community development with nature in the United States, aiming to establish a systematic ecological function network. With economic development, "green infrastructure" has shifted more towards the ecological infrastructure engineering proposed by Moffatt, which focuses on environmentally friendly infrastructure in multiple aspects, such as renewable energy, sewage discharge, and transportation [16]. In terms of the motivation for urban green-infrastructure investment, existing research has examined the impact of environmental regulation on the decision-making and behavior of green investment entities, arguing that environmental protection goals and regulations are key drivers of urban green-infrastructure investment [17]. The planning of green-infrastructure investment projects for this purpose is often based on the environmental assessment of the project facilities (EIA) [18]. Dai et al. pointed out that the impact of environmental regulation on green investment efficiency is also moderated by factors such as the direction of economic growth, financing constraints, and urban industrial structure [19]. In addition, improving residents' quality of life and facilitating urban economic operations are also important objectives of green-infrastructure investment [20]. To better leverage the effects of green-infrastructure investment, many studies have explored its relationship with nature-based solutions (NBS), suggesting that green-infrastructure investment combined with NBS has advantages in ecological restoration and improving capital utilization efficiency [21,22]. In terms of the impact of urban green-infrastructure investment, Zhao's research indicates that green investment has significant economic, social, and environmental effects [23]. First, green-infrastructure investment can optimize the allocation of factors, leading to adjustments in energy structure, industrial structure, and consumption patterns towards greener models. Second, increased green-infrastructure investment will promote the development of a harmonious coexistence between humans and nature in cities. This is achieved through higher urban greening levels and a greater share of the green economy, which enhances urban livability and has positive effects on social stability and talent attraction [24]. Third, Almulhim et al. found that increased green-infrastructure investment provides strong financial support for cities to protect the environment and develop eco-friendly economies, effectively promoting the protection and development of urban ecological environments and thereby supporting the sustainability of urban economic growth [25]. In terms of the mechanism of green-infrastructure investment, existing research has examined its impact on related industries, the job market, and resource utilization efficiency. Li et al. found that urban green-infrastructure investment can drive the development of related industries such as renewable energy equipment manufacturing and green building construction, promoting urban economic structural upgrading and creating numerous job opportunities [26]. At the same time, green-infrastructure investment also improves urban resource utilization efficiency, reduces energy consumption in economic activities, minimizes energy waste, and lowers urban operating costs.

2.2. The Meaning, Measurement, and Optimization Pathways of Urban Economic Sustainable Development

Simmie's research indicates that the capability of sustainable urban economic development refers to a city economy's ability to withstand, adjust to, and transform in the face of

adverse shocks and economic fluctuations [27]. Urban economic resilience not only reflects a city's ability to adapt to and recover from external shocks such as economic volatility and environmental crises but also represents its core mechanism for promoting efficient resource allocation, industrial innovation, and inclusive social growth. Through diversified industrial structures, green technology applications, and equitable policy design, economic resilience enables cities to ensure stable economic operations while reducing dependence on non-renewable resources, lowering environmental burdens, and promoting social equity. This ultimately achieves long-term coordination of environmental, economic, and social benefits, which is highly consistent with the key dimensions of sustainable development goals [28]. Therefore, urban economic resilience levels can be used to measure sustainable urban economic development capabilities. The measurement of urban economic resilience can be broadly divided into single-dimensional indicator methods [29] and comprehensive indicator system evaluation methods. Chao et al. used the deviation of a city's actual gross domestic product from that of 2008 to measure economic resilience levels [30]. The comprehensive indicator system evaluation method, on the other hand, constructs a multi-dimensional composite indicator system to measure urban economic resilience levels, thereby achieving a more comprehensive measurement [31]. Research on the optimization pathways of economic sustainable development levels has examined factors such as industrial structure diversification and agglomeration effects. It suggests that enhancing industrial structure diversification and promoting urban factor agglomeration can significantly improve sustainable urban economic development levels [32]. Technological spillover effects can also help economic systems quickly adapt to and mitigate risks and challenges, driving continuous and stable urban economic development [33]. With the development of the digital economy and increased attention to policy shocks, some studies have also examined the impact of digital economic development and industrial policy shocks on sustainable urban economic development levels [34]. Overall, research on sustainable urban economic development levels has preliminarily outlined the basic framework for exploring the stability of urban economic systems.

2.3. The Relationship Between Urban Green-Infrastructure Investment and Urban Economic Sustainable Development

In terms of impact, scholars have generally focused on the role of urban green-infrastructure investment in enhancing urban economic recovery and risk resistance capabilities. Zeng et al., based on panel data models, verified the significant positive effect of green-infrastructure investment on sustainable urban economic development, confirming that the process of green-infrastructure investment can significantly enhance a city's recovery and adaptation capabilities in the face of external shocks [35]. This conclusion provides important theoretical support for understanding the role of green-infrastructure investment in enhancing economic sustainability. Nie et al. examined the impact of green-infrastructure investment on urban technological innovation and found that it mainly relies on multiple driving mechanisms, such as technological innovation and industrial collaboration [36]. Liu et al. further revealed that green-infrastructure investment can effectively promote urban policy support and collaborative governance, enabling cities to obtain more policy resources and thereby enhance economic sustainability [37]. Wang et al.'s study of multiple U.S. cities showed that green-infrastructure investment significantly promotes sustainable urban economic development through mechanisms such as improving urban ecological environments and enhancing resource utilization efficiency [38]. Lv et al.'s research on Chinese cities revealed a "U"-shaped dynamic relationship between green-infrastructure investment and economic sustainable development, characterized by initial suppression followed by promotion [39]. This conclusion was further confirmed in subsequent studies by Wang et al. [40], providing important theoretical evidence for

understanding the dynamic relationship between green-infrastructure investment and economic sustainable development.

In summary, existing research has achieved certain results in the area of urban green-infrastructure investment and sustainable urban economic development, but there are still the following shortcomings: ① Insufficient data basis: Existing research mainly focuses on a few cities or regions and lacks a comprehensive analysis of different types of cities nationwide. It also fails to examine the differences in the relationship between green-infrastructure investment and sustainable urban economic development levels among cities with different economic development levels and industrial structures. ② Incomplete indicator measurement: Existing research on measuring urban green-infrastructure investment often focuses on a single dimension, lacking comprehensiveness and failing to reflect the true situation of urban green-infrastructure investment. ③ Insufficient mechanism research: Existing research lacks a systematic analysis of the mechanisms through which urban green-infrastructure investment enhances urban economic resilience through pathways such as industrial chain resilience, ecological resilience, and talent agglomeration. ④ Existing research has not paid attention to the spatial spillover effects of urban green-infrastructure investment on sustainable urban economic development levels and lacks relevant analysis. Based on this, this paper conducts a series of empirical analyses based on data from 281 Chinese cities over 13 years to scientifically analyze the impact of urban green-infrastructure investment on economic sustainable development levels, aiming to provide references for urban economic development in China.

Compared with existing research, the innovations of this paper are as follows:

① A comprehensive evaluation indicator system is extensively used to avoid the problem of incomplete indicator measurement in existing research, enhancing the objectivity and scientific nature of the study.

② Multiple econometric models, such as machine learning, quantile regression, and the generalized method of moments, are employed. Various robustness tests, including IV-2SLS models and PCA principal component analysis, are used to verify the robustness of the benchmark regression results.

③ While examining the direct impact of urban green-infrastructure investment on sustainable urban economic development, this paper also explores the impact mechanisms from multiple dimensions, such as industrial chain resilience, ecological resilience, and talent agglomeration. This enriches the understanding of the effects of urban green-infrastructure investment in academia and reveals the causal pathways through which urban green-infrastructure investment impacts sustainable urban economic development.

④ Considering the characteristics of each city, this paper deeply discusses the heterogeneity of the impact of urban green-infrastructure investment based on traits such as location, resource conditions, and openness, leading to more specific conclusions.

⑤ Since current research pays little attention to the spatial spillover effects of urban green-infrastructure investment on economic sustainable development, this paper attempts to use the spatial Durbin model to examine the impact of urban green-infrastructure investment on sustainable urban economic development, providing policy references for cities to increase green-infrastructure investment.

3. Mechanism Analysis and Research Hypothesis

3.1. Industrial Structure Upgrading Effect

First, urban infrastructure investment enhances a city's risk resistance by optimizing resource allocation. Specifically, it improves basic conditions like transportation, energy, and communication, boosting urban operational and resource utilization efficiency [41].

This not only increases economic efficiency but also strengthens the city's ability to cope with external shocks.

Second, infrastructure investment spurs technological innovation in related industries, promoting the application of new technologies, materials, and processes [42]. For example, building intelligent transportation systems can enhance traffic management intelligence, reducing accidents and congestion. Increasing green-infrastructure investment in cities will accelerate the development of green technologies and industries [43], advancing the city's green and sustainable development and its ability to resist disturbances.

Third, the implementation of urban infrastructure investment requires policy support from the government. By formulating and enforcing relevant policies, the smooth execution of infrastructure projects can be ensured. Thus, the development of urban green-infrastructure investment can also drive policy support and collaborative governance, providing vital institutional support for urban economic sustainability [44]. As macroeconomic regulation becomes more important, infrastructure investment will play an increasingly crucial role in urban economic development. Based on this, the following hypotheses are proposed in this study:

Hypothesis H1. *Regional integration policies have a significant promoting effect on urban green and urban sustainable development levels.*

3.2. Industrial Agglomeration Effect

The main factors affecting sustainable urban economic development include industrial chain resilience, ecological environment resilience, and talent supply resilience. Investment in urban green infrastructure enhances the city's resource utilization and risk resistance by boosting the resilience of the industrial chain, ecological environment, and talent supply [45]. This drives the transformation of industrial economies towards high-speed, coordinated, and sustainable development, thereby optimizing urban economic development models and promoting green and low-carbon transitions. Ultimately, it improves urban economic sustainability.

① Industrial Chain Resilience Enhancement Effect: First, investment in urban green infrastructure can optimize basic conditions such as transportation, energy, and communication by accelerating the construction of public transportation networks and energy pipelines [46]. This improves urban operational and resource utilization efficiency. By optimizing resource allocation, it significantly enhances the efficiency of the urban industrial chain and strengthens its ability to cope with external shocks. Second, increasing investment in green infrastructure can drive technological innovation in related industries and promote the development of green technologies, new materials, and derivative industries [47]. This enhances the adaptability of the urban industrial chain to rapid changes in the economic environment and boosts the city's overall competitiveness. Third, governments can encourage private capital participation in green infrastructure construction through policies such as financial subsidies and tax incentives [48]. This optimizes policy support and enhances the resilience of the industrial chain.

Industrial chain resilience is a crucial component of sustainable urban economic development. Its impact on urban economic sustainability mainly includes increasing economic recovery speed, reducing economic fluctuation risks, and enhancing urban risk resistance. First, stronger industrial chain resilience significantly accelerates economic recovery following external shocks such as natural disasters or economic crises [49]. When all links of the industrial chain are highly resilient, cities can quickly resume production activities and minimize economic losses. Second, cities with stronger industrial chain resilience have higher resource allocation efficiency and adaptability. They can better cope with demand changes and market fluctuations [50]. When one industry is impacted,

other links in the chain can adjust production strategies or find alternative suppliers to reduce dependence on a single industry, thereby lowering overall economic fluctuation risks [51]. This enhances urban economic sustainability. Third, stronger industrial chain resilience means greater resistance to external shocks. Cities can better ensure the stable and orderly operation of key infrastructure and core economic activities during external shocks, significantly reducing economic risks from supply chain disruptions or production halts. This plays an important role in improving urban economic sustainability. Based on this, the following hypothesis is proposed:

Hypothesis H2. *Urban green-infrastructure investment promotes the enhancement of sustainable urban economic development levels through the effect of enhancing industrial chain resilience.*

② Ecological Environment Resilience Enhancement Effect: First, investment in urban green infrastructure can improve air quality and water quality by constructing more robust wastewater and exhaust emission monitoring systems to strictly oversee urban discharges [52]. This investment also provides necessary funding for increasing urban green spaces, enhancing ecological functions, and significantly boosting ecological resilience. Second, investing in green infrastructure such as rain gardens and wetlands can reduce urban flooding and enhance water self-purification capabilities, thereby stabilizing urban ecosystems [53]. Third, investment in renewable energy facilities and energy-efficient buildings can reduce dependence on traditional energy sources, improve energy efficiency, and mitigate pollution from fossil fuel consumption, effectively enhancing ecological quality.

The promotion of urban economic sustainability by ecological resilience is twofold. First, it reduces economic operation costs. Cities with high ecological resilience can minimize economic losses and post-disaster reconstruction costs during natural disasters like floods through wetland and flood control construction [54]. Additionally, a healthy environment reduces health issues caused by pollution, lowering medical and social security expenditures, alleviating fiscal burdens, and enhancing economic resilience and sustainability [55]. Second, it enhances economic risk resistance. Cities with strong ecological resilience can better withstand external shocks and reduce the risk of economic activity disruptions. For example, rainwater collection and wastewater treatment systems can mitigate risks from water scarcity and pollution. Moreover, a good environment boosts residents' sense of belonging and happiness, reducing economic risks and social unrest caused by instability [56]. Based on this, the following hypothesis is proposed:

Hypothesis H3. *Urban green-infrastructure investment promotes sustainable urban economic development through the enhancement of ecological resilience.*

③ Agglomeration Effect: Talent is the core driver of urban economic development [57]. Green-infrastructure investment spurs related industries like renewable energy equipment manufacturing, green building construction, and ecological restoration, creating jobs and attracting talent. Second, this investment funds infrastructure improvements, optimizing research environments and attracting high-tech and innovative talent, boosting urban competitiveness [58]. Third, by enhancing livability through better ecological quality and recreational spaces like parks and wetlands, green infrastructure significantly increases urban talent attractiveness [59]. The addition of modern green infrastructure, such as green buildings and smart transportation, also improves the city's overall image, attracting more high-tech and innovative talent.

The role of talent agglomeration in enhancing urban economic sustainability is threefold. First, high-quality talent drives technological innovation, improving technological and production levels, efficiency, and resource utilization, and accelerating economic growth

and resilience. Second, talent agglomeration creates a more flexible labor market, reducing unemployment caused by skill mismatches during economic crises [60], stabilizing employment, and enhancing sustainability. Third, high-quality talent, with rich technical reserves [61], can quickly develop and apply new technologies and approaches during emergencies like natural disasters or pandemics, improving emergency response capabilities, reducing losses, and boosting economic sustainability. Based on this, the following hypothesis is proposed:

Hypothesis H4. *Urban green-infrastructure investment promotes sustainable urban economic development through the talent agglomeration effect.*

3.3. Spatial Spillover Effects

This study further examines the spatial spillover mechanisms of urban green-infrastructure investment on sustainable urban economic development. First, based on agglomeration and selection effects [62], green-infrastructure investment guides the tertiary sector to core cities with advanced economies and technology while shifting the secondary sector to surrounding areas. This accelerates regional industrial upgrading, curbs the expansion of high-energy-consuming and polluting enterprises, and fosters green industry growth points. Second, urban infrastructure development strengthens inter-city network connections. Through interconnected infrastructure and cross-regional resource sharing, it significantly enhances the spatial diffusion efficiency of economic sustainability promotion effects [63]. Additionally, research confirms that environmental regulation has positive spatial spillover effects [64]. Green-infrastructure investment, through policy coordination and standard alignment, forms cross-regional environmental governance communities. Advanced cities drive less developed areas through technological spillovers and institutional demonstrations, promoting spatial diffusion of economic development. Based on this, the following hypothesis is proposed:

Hypothesis H5. *Urban green-infrastructure investment has a positive spatial spillover effect on sustainable urban economic development capabilities.*

Figure 1 is the research framework diagram of this paper.

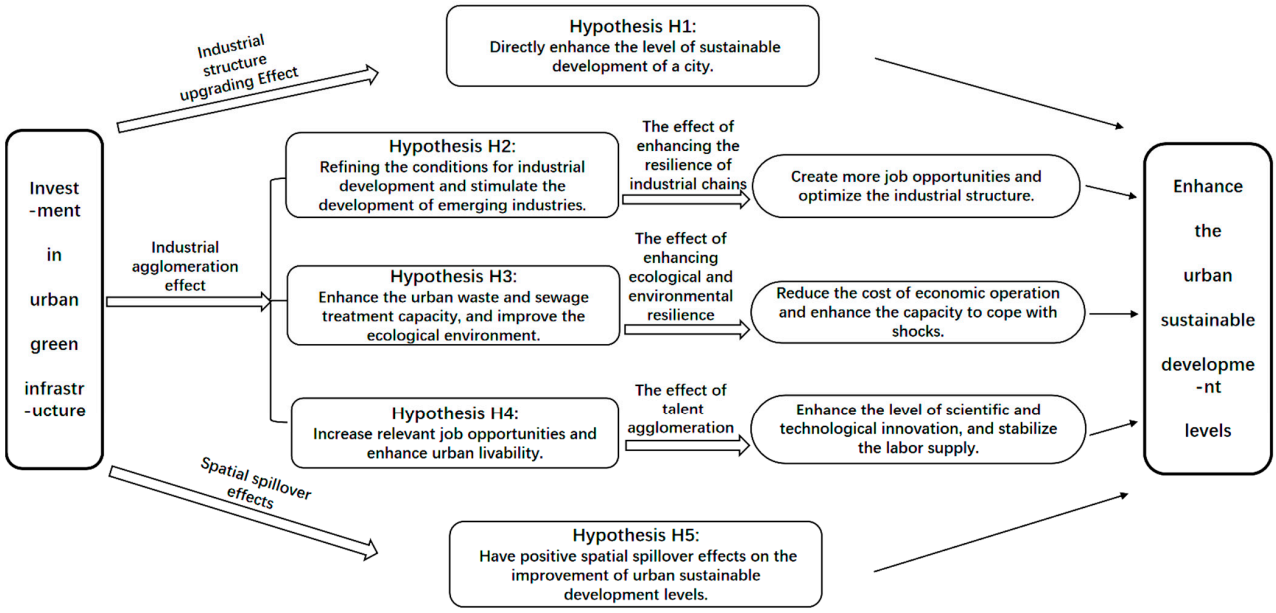

Figure 1. Research framework diagram.

Overall, urban green-infrastructure investment not only directly enhances urban economic sustainability but also boosts economic resilience and sustainability through improved industrial chain resilience, ecological resilience, and talent focus. Moreover, this investment also has a positive spatial spillover effect, meaning that the promotion of economic sustainability in one city can spread to surrounding cities.

4. Research Design

4.1. Model Specifications

To empirically examine the impact of urban green-infrastructure investment on sustainable urban economic development levels, drawing on the research by Zhang et al. [65], the econometric model is specified as follows:

$$Ecores_{kt} = \beta_0 + \beta_1 Score_{kt} + \beta_2 Controls_{kt} + \zeta_k + \delta_t + \varepsilon_{kt} \quad (1)$$

In Model (1), which is employed to analyze the impact of green-infrastructure investment on economic resilience in cities, the dependent variable is denoted as $Ecores_{kt}$, representing the level of green-infrastructure investment for city k in year t; the independent variable is $Score_{kt}$, indicating the level of sustainable development for city k in year t. $Controls_{kt}$ represents a set of city-level control variables. ζ_k signifies regional fixed effects, δ_t denotes time fixed effects, and ε_{kt} is the stochastic error term of the equation. The coefficient β_1 is the primary parameter of interest for estimation. A significant positive value of β_1 would suggest that green-infrastructure investment significantly enhances the level of urban sustainable development.

4.2. Variable Explanation

(1) Dependent Variable: Given that sustainable urban economic development capabilities can be measured by urban economic resilience, and that urban economic resilience can be assessed from three core perspectives—resistance and recovery capacity, adjustment and adaptation capacity, and optimization and transformation capacity [66]—this study adopts the entropy method to construct an Urban Economic Sustainable Development Level Index (Ecores). The entropy method, as an objective weighting approach, effectively minimizes subjective influences on weight determination, thereby enhancing data objectivity. Drawing on the research of Zhang et al. and Ding et al. [67,68], the Ecores index measures sustainable urban economic development from three aspects: resistance and recovery capacity (Res), adjustment and adaptation capacity (Adp), and optimization and transformation capacity (Tran). A higher index value indicates a higher level of sustainable urban economic development. The weights of each indicator, determined by the entropy method formula, are detailed in Appendix A, and the entropy measurement system is presented in Table 1.

(2) Independent Variable: Construct the urban green-infrastructure investment level variable Score. Given that key urban green-infrastructure investments typically focus on sewage transportation capacity, public transportation development, and urban greening, the reasons are as follows: First, sewage transportation capacity is a vital part of urban infrastructure. With urban growth and population increase, sewage generation rises. Enhancing sewage transportation can safely and efficiently convey sewage from all urban areas, preventing random discharge and environmental pollution, thereby protecting the urban environment. Second, improving public transportation is crucial for urban economic sustainability. A good public transit system can alleviate traffic congestion, reduce private car use, and lower energy consumption and exhaust emissions, thus improving environmental quality. Third, urban greening is an important measure for improving the

urban ecological environment. Green spaces can absorb carbon dioxide, release oxygen, regulate local climate, and mitigate urban heat-island effects. Additionally, green areas provide recreational spaces for residents, enhancing their quality of life and overall urban livability. Based on this, this study, drawing on the research of Yu et al. [69], constructs a green-infrastructure investment level index using the entropy method. The specific calculation system for the index is shown in Table 2.

Table 1. Measurement system of urban economic resilience indicators.

First-Level Indicator	Second-Level Indicator	Third-Level Indicator	Indicator Weight	Indicator Attribute
Economic Sustainable Development Levels	Capability of Resistance and Recovery (Res) 0.1803	Per Capita Regional Gross Domestic Product (CNY)	0.0467	+
		Disposable Income of Urban Residents (CNY)	0.0208	+
		Savings Balance of Urban and Rural Residents (CNY)	0.0010	+
		Number of Registered Unemployed in Urban Areas (persons)	0.1096	-
		Ratio of Total Imports and Exports to GDP (%)	0.0022	-
	Capability of Adjustment and Adaptation (Adp) 0.2339	Local Fiscal Revenue–Expenditure Ratio (%)	0.0237	+
		Total Retail Sales of Consumer Goods (CNY ten thousand)	0.0959	+
		Tertiary Industry's Share in GDP (%)	0.0072	+
		Year-End Financial Institutions' Loan–Deposit Ratio (%)	0.0232	+
		Fixed Asset Investment (CNY ten thousand)	0.0839	+
	Capability of Optimization and Transformation (Opt) 0.5859	Number of Patent Grants (items)	0.1826	+
		Number of Students in General Higher Education Institutions (ten thousand persons)	0.0864	+
		Fiscal Expenditure on Science (CNY ten thousand)	0.0812	+
		Fiscal Expenditure on Education (CNY ten thousand)	0.2357	+

Table 2. Measurement system of indicators for urban green-infrastructure investment levels.

First-Level Indicator	Second-Level Indicator	Third-Level Indicator	Indicator Weight	Indicator Attribute
Level of Urban Green-Infrastructure Investment	Capacity of Urban Sewage Conveyance 0.3607	Annual Urban Sewage Discharge Volume (ten thousand cubic meters)	0.1940	+
		Length of Urban Sewage Discharge Pipelines (kilometers)	0.1667	+
	Development Level of Urban Public Transport 0.3321	Number of Taxis in Urban Areas at Year-end (thousand vehicles)	0.1689	+
		Number of Urban Public Transport Buses at Year-end (thousand vehicles)	0.1632	+
	Level of Urban Greening Construction 0.3071	Urban Green Space Area (square kilometers)	0.0258	+
		Urban Greening Rate (%)	0.2812	+

(3) Control Variables: Considering that other factors at the urban level may potentially impact urban sustainable development, this study follows established practices by selecting factors that may influence urban sustainable development as control variables [70]. These mainly include the following aspects, with the measurement of control variables detailed in Table 3:

① Urban Hukou Population (LnPop): The number of urban hukou (household registration) population directly affects the labor supply, consumer demand, and public service requirements of a city. A larger hukou population implies a more abundant labor supply and greater demand for consumption and public services [71]. This, in turn, influences the city's economic system's ability to cope with certain shocks and has a significant impact on urban economic development and sustainable development capabilities, thus necessitating its inclusion in the analysis.

② Level of Economic Development (AvGDP): GDP is a crucial indicator of the economic scale and total volume of economic activities in a region, reflecting a city's economic strength and development level. Generally, cities with higher GDP levels have a stronger economic foundation and more financial and economic resources, which enhances their capacity to withstand external shocks [72]. This is an important factor influencing urban sustainable development.

③ Urban Industrial Structure (Ind): Different industries rely on distinct resource markets. A diverse industrial structure within a city can enhance its economic adaptability and flexibility. When one industry is impacted, others can provide a buffer, reducing overall economic fluctuations [73]. Moreover, the upgrading of urban industrial structures increases the proportion of high value-added and resource-efficient industries such as services [74], which can significantly boost the level of urban sustainable development.

④ Degree of Government Intervention (Gov): A higher degree of government intervention in urban development and market activities often drives urban industries towards more rational, greener, sustainable, and forward-looking directions. Existing research has found that cities with higher levels of government intervention have stronger capabilities to resist economic shocks and natural disasters [75]. Therefore, the degree of government intervention is included as a control variable in this study.

⑤ Urban Innovation Investment Level (Fin): Increased innovation investment in cities can promote technological progress and industrial upgrading, enhancing the city's competitiveness and adaptability to change [76]. Moreover, higher innovation investment can help nurture emerging industries in cities, creating new growth points and significantly strengthening the city's economic sustainable development capabilities.

Table 3. Measurement of control variables.

Variable	Symbol	Definition
Urban registered population	LnPop	The logarithm of the urban registered population at year-end (ten thousand people)
Urban economic development level	AvGDP	Urban per capita GDP (CNY ten thousand)
Urban industrial structure	Ind	The proportion of the value of the tertiary industry to the total industrial value in the city
Degree of government intervention	Gov	The proportion of urban fiscal expenditure (CNY ten thousand) to GDP (CNY ten thousand)
Urban innovation input level	Inv	The total amount of urban innovation investment (CNY hundred million)

(4) Data Sources: This study selects panel data from Chinese prefecture-level cities from 2010 to 2022 as the research sample. All indicator data for each city is sourced from the *China City Statistical Yearbook*, *China Energy Yearbook*, and local government work reports. Before conducting econometric regressions, to avoid the influence of extreme values on the results, the following standardization processes are applied to the raw data: (1) Cities with a data missing rate of over 15% are excluded; (2) Linear interpolation is used to fill in non-consecutive missing values. This results in a balanced panel dataset covering 281 prefecture-level cities; (3) In the section on spatial spillover effects of policies, this study calculates a spatial economic and geographical nested matrix among Chinese cities, comprehensively measuring the distances between cities from both GDP and geographical coordinates (latitude and longitude) perspectives. Descriptive statistics of the variables are presented in Table 4.

Table 4. Descriptive statistics.

Variable	N	Mean	SD	Min	Max
EcoRes	3653	0.1308	0.0732	0.0285	0.7633
Score	3653	0.0463	0.0721	0.0050	0.7646
Res	3653	0.0497	0.0841	0.0012	0.8885
Adp	3653	0.0352	0.0599	0.0001	0.9958
Trans	3653	0.0535	0.0918	0.0002	0.9494
lnPop	3653	5.9051	0.6906	2.9704	8.1362
AvGdp	3653	5.5000	3.4769	0.5304	46.7749
Ind	3653	42.2225	10.1283	14.3600	83.8700
Gov	3653	0.1965	0.0966	0.4389	1.4852
Inv	3653	2.0704	4.2371	0.0015	57.4385

5. Empirical Results Analysis

5.1. Benchmark Regression Analysis

Prior to constructing the specific model, this study first conducted a correlation analysis among the variables selected for the model. The random forest method was employed to fit the explanatory power of the core independent variables and control variables on the dependent variable, yielding an R^2 value of 0.996. This indicates that the core independent variables and control variables selected in this study can effectively explain the dependent variable, thereby ruling out the issue of omitted variable bias. Subsequently, the gradient-boosting decision tree method was utilized to assess the importance of the core independent variables and control variables within the model. The regression results from the gradient-boosting decision tree reveal that the factors influencing urban sustainable development, in descending order of weight, are urban green-infrastructure investment, urban hukou population, urban innovation investment, level of urban economic development, urban industrial structure, and degree of government intervention. This finding corroborates the rationality of selecting green-infrastructure investment as the core independent variable in this study. Finally, the Hausman test was conducted. With a Hausman test value of 286 and a *p*-value of 0.000, the results indicate that the fixed-effects model is more appropriate for examining the causal relationship between urban green-infrastructure investment and urban sustainable development. Therefore, this study employs a two-way fixed-effects model, controlling for both time and city factors, for the benchmark regression analysis, and further conducts quantile regression based on the benchmark regression.

Building on the aforementioned tests, this study empirically examines the impact of urban green-infrastructure investment on urban sustainable development. Table 5 presents the estimation results of the effect of urban green-infrastructure investment on urban sustainable development. After controlling for individual and time fixed effects, Column (1) in Table 5 shows that the coefficient of Score is 0.0588 and significant at the 1% level. This suggests that urban green-infrastructure investment significantly enhances the level of urban sustainable development, bolstering the city's capacity to cope with external risks. The results in Columns (2), (3), and (4) further support this conclusion. The quantile regression results in Table 6 indicate that the coefficient of Score is positive and significant across all quantiles, demonstrating a positive impact of green-infrastructure investment on urban sustainable development. Moreover, the coefficient of Score increases from 0.174 at the 10th quantile to 0.333 at the 90th quantile, suggesting that the marginal benefits of green-infrastructure investment are greater in cities with higher levels of sustainable development. The chart of quantile regression results is shown in Figure 2. Overall, urban green-infrastructure investment has a significant positive effect on urban sustainable development, thereby validating Hypothesis H1.

Table 5. Baseline regression results.

Variables	(1) EcoRes	(2) Res	(3) Adp	(4) Trans
Score	0.0588 ***	0.247 ***	0.3537 ***	0.4455 ***
	(0.0121)	(0.0121)	(0.0093)	(0.0167)
LnPop	0.0908 ***	0.0812 ***	0.0494 ***	0.0631 ***
	(0.0047)	(0.0043)	(0.0037)	(0.0043)
AvGDP	0.00748 ***	0.0066 ***	0.0064 ***	0.0061 ***
	(0.0002)	(0.0002)	(0.0001)	(0.0001)
Ind	0.0021 ***	0.0020 ***	0.0020 ***	0.0022 ***
	0.0001	0.0000	0.0000	0.0001
GOV	−0.0036	0.0012	−0.0025	−0.0039
	(0.0062)	(0.0056)	(0.0046)	(0.0054)
InvInn	0.0058 ***	0.0055 ***	0.0023 ***	0.0052 ***
	(0.0002)	(0.0003)	(0.0002)	(0.0002)
Constant	−0.5501 ***	−0.4947 ***	−0.2971 ***	−0.3949 ***
	(0.0274)	(0.0254)	(0.0214)	(0.0249)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	3653	3653	3653	3653
R^2	0.776	0.799	0.854	0.816

Standard errors in parentheses, *** $p < 0.01$.

Table 6. Quantile regression results.

Variables	10th Percentile (1)	20th Percentile (1)	50th Percentile (2)	75th Percentile (3)	90th Percentile (4)
Score	0.1740 ***	0.1971 ***	0.2402 ***	0.2573 ***	0.3336 ***
	(0.0191)	(0.0157)	(0.0167)	(0.0302)	(0.0206)
LnPop	0.0152 ***	0.0145 ***	0.0141 ***	0.0139 ***	0.0117 ***
	(0.0012)	(0.0008)	(0.0007)	(0.0005)	(0.0006)
AvGDP	0.0057 ***	0.00665 ***	0.00688 ***	0.00803 ***	0.00742 ***
	(0.0003)	(0.0003)	(0.0002)	(0.0003)	(0.0004)
Ind	0.0018 ***	0.0016 ***	0.0015 ***	0.0015 ***	0.0017 ***
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0000)
GOV	−0.0306 ***	−0.0198 ***	−0.0143 ***	−0.0131 ***	−0.0119 *
	(0.0036)	(0.0027)	(0.0030)	(0.0032)	(0.0068)
InvInn	0.0031 ***	0.00415 ***	0.00536 ***	0.00608 ***	0.00687 ***
	(0.0006)	(0.0004)	(0.0005)	(0.0005)	(0.0006)
Constant	−0.0939 ***	−0.0850 ***	−0.0767 ***	−0.0739 ***	−0.0596 ***
	(0.0079)	(0.0055)	(0.0043)	(0.0036)	(0.0047)
City	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
N	3653	3653	3653	3653	3653
R^2	0.602	0.667	0.730	0.790	0.834

Standard errors in parentheses, *** $p < 0.01$, * $p < 0.1$.

5.2. Mechanism Test Results

Urban green-infrastructure investment effectively promotes the enhancement of sustainable urban economic development by improving the resilience of the industrial chain, ecological environment, and talent agglomeration level. Drawing on the research of Wen et al., this study conducts mechanism tests on the above three channels [77].

For the industrial chain resilience enhancement effect**, this study references the research of Chen et al. [78] and uses the entropy method to comprehensively represent industrial chain resilience (IndRes) from two dimensions: urban resistance and recovery capacity and transformation and renewal capacity. The empirical results in Column (1) of Table 7 show that the coefficient of Score is 0.0114, which is significantly positive at the 1% level. This indicates that urban green-infrastructure investment significantly enhances

urban industrial chain resilience. The possible reasons are as follows: First, green infrastructure, such as eco-parks and green transportation networks, can reduce corporate operating costs and improve resource utilization efficiency [79], thereby enhancing enterprises' resistance and recovery capabilities in the face of external shocks. Second, green-infrastructure investment promotes collaborative innovation among industries and drives traditional industries to transform in a green and low-carbon direction, enhancing the adaptability and flexibility of industries [80]. The improvement of industrial chain resilience can enhance the ability of each link in the urban industrial chain to resist external shocks, ensure the stability of key urban infrastructure and core economic activities in the face of shocks, and improve urban economic resilience.

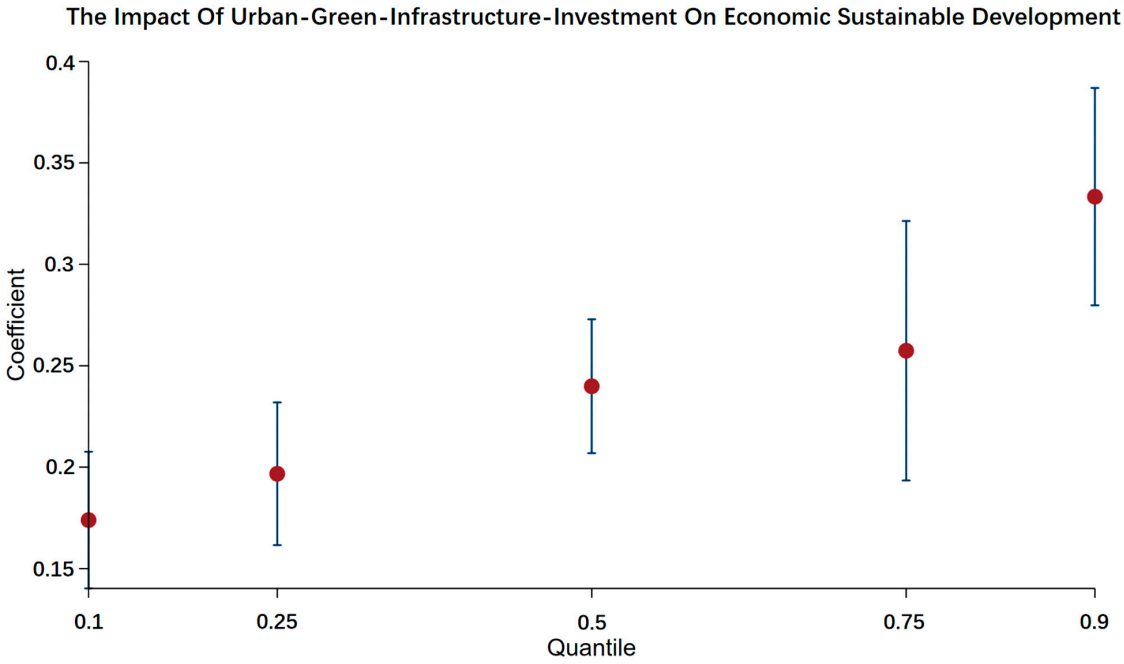

Figure 2. Quantile results plot.

Further, the study uses the Sobel–Goodman method to enhance the reliability of the mechanism test results, as shown in Columns (2)–(4) of Table 7. It can be concluded that IndRes plays a significant mediating role between Score and EcoRes, consistent with the findings of Fang et al. [81].

In terms of ecological resilience enhancement, urban green-infrastructure investment improves environmental resilience by constructing disaster-resistant facilities, establishing protection mechanisms and organizations, enhancing disaster-resistance capabilities, improving ecosystem functions, and promoting sustainable resource use. Enhanced environmental resilience reduces risks to the economy from external shocks such as disasters and enhances economic stability. The development of environmental protection also promotes industrial transformation and attracts investment towards green emerging industries [82], thereby improving economic sustainability and urban economic resilience. Based on the core factors affecting urban environmental development, which are urban manufacturing activities, and considering the level of environmental disturbance reflected by green total factor productivity (GTFP) in urban economic activities, this study, drawing on the research of Li et al., uses the super-efficiency SBM model to measure urban GTFP as an indicator of urban ecological resilience [83]. The specific calculation formula is shown in Appendix B. The results in Column (1) of Table 8 show that the coefficient of Score is 1.283, which is significantly positive at the 1% level. This indicates that urban green-infrastructure investment significantly enhances urban GTFP, thereby improving ecological resilience and

promoting the growth of urban economic resilience. Columns (2)–(4) further attest to the role of this mechanism.

Table 7. Mechanism tests (1).

Variables	Stepwise Regression Method		Sobel–Goodman Method	
	IndRes (1)	EcoRes (2)	IndRes (3)	EcoRes (4)
Score	0.0114 ***	0.2352 ***	0.1188 ***	0.2032 ***
	(0.0041)	(0.0101)	(0.0141)	(0.0106)
IndRes	-	-	-	0.2728 ***
				(0.0121)
LnPop	0.0272 ***	0.0152 ***	0.0045 ***	0.0147 ***
	(0.0016)	(0.000)	(0.0014)	(0.0017)
AvGDP	0.0004 ***	0.0062 ***	0.0022 ***	0.0057 ***
	(0.0001)	(0.0003)	(0.0001)	(0.0000)
Ind	−0.0000	0.0028 ***	0.0000	0.002 ***
	0.0000	(0.0002)	(0.0000)	(0.0001)
GOV	0.00473 **	−0.0276 ***	0.0425 ***	−0.0382 ***
	(0.0021)	(0.0040)	(0.0067)	(0.0044)
Inv	0.0021 ***	0.0051 ***	0.0073 ***	0.0037 ***
	(0.0001)	(0.0001)	(0.0004)	(0.0002)
Sobel Z	-	-	-	7.8751 ***
				(0.0042)
Constant	−0.1461 ***	−0.0862 ***	−0.0447 ***	−0.0746
	(0.0093)	(0.0041)	(0.0064)	(0.0032)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	3653	3653	3653	3653
R^2	0.412	0.927	0.731	0.938

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$.

Table 8. Mechanism tests (2).

Variables	Stepwise Regression Method		Sobel–Goodman Method	
	GTFP (1)	EcoRes (2)	GTFP (3)	EcoRes (4)
Score	1.283 ***	0.2350 ***	0.2282 ***	0.2374 ***
	(0.130)	(0.0102)	(0.0534)	(0.0102)
GTFP	-	-	-	0.0085 **
				(0.0013)
LnPop	0.0226	0.0157 ***	0.0118 ***	0.0151 ***
	(0.0361)	(0.0016)	(0.0034)	(0.0011)
AvGDP	0.0045 ***	0.0062 ***	0.0061 ***	0.006 ***
	(0.0012)	(0.0001)	(0.0012)	(0.000)
Ind	0.0017 ***	0.0021 ***	0.0017 ***	0.0021 ***
	(0.0003)	(0.0000)	(0.0005)	(0.0000)
GOV	−0.0869 **	−0.0277 ***	0.1387 ***	−0.0285 ***
	(0.0384)	(0.0049)	(0.0226)	(0.0042)
Inv	0.0045 ***	0.0052 ***	−0.0021 *	0.0051 ***
	(0.0015)	(0.0000)	(0.0002)	(0.0030)
Sobel Z	-	-	-	2.0587 ***
				(0.0014)
Constant	0.0718	−0.0862 ***	−0.2133 ***	−0.0741
	(0.2120)	(0.0040)	(0.0217)	(0.0032)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	3653	3653	3653	3653
R^2	0.529	0.914	0.754	0.927

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Considering the key role of scientific research and technical talent in urban economic development, this study, drawing on the research of Gao et al., uses the entropy method to measure the talent agglomeration effect (TalGath) from three dimensions: the number of practitioners (in ten thousand people) in scientific research, technical services, and education in the city in the current year [84]. The results in Column (1) of Table 9 show that the coefficient of Score is 1.031, which is significantly positive at the 1% level. This indicates that urban green-infrastructure investment significantly promotes the agglomeration of high-tech talent in cities. The possible reasons are as follows: First, urban green-infrastructure investment drives the improvement of the urban ecological environment, enhancing urban livability, attractiveness, and competitiveness [85]. Second, it guides the development of emerging industries, creating more job opportunities for high-tech talent. These aspects jointly create a favorable working and living environment and broad development space for high-tech talent, thereby significantly promoting their agglomeration in cities. The agglomeration of high-tech talent strongly promotes urban technological development and economic transformation, improves environmental protection levels, enhances urban innovation and anti-interference capabilities [86], and improves urban economic sustainability. Columns (2)–(4) further verify the role of this mechanism.

Table 9. Mechanism tests (3).

Variables	Stepwise Regression Method	Sobel–Goodman Method		
	TalGath (1)	**EcoRes** (2)	**TalGath** (3)	**EcoRes** (4)
Score	1.0311 ***	0.2352 ***	0.2223 ***	0.2091 ***
	(0.0397)	(0.0105)	(0.0210)	(0.0106)
TalGath	-	-	-	0.1190 ***
				(0.0081)
LnPop	0.1277 ***	0.0152 ***	−0.0032 **	0.0160 ***
	(0.0094)	(0.0001)	(0.0014)	(0.001)
AvGDP	0.0009 **	0.0069 ***	−0.0051 ***	0.0056 ***
	(0.0004)	(0.0000)	(0.000)	(0.0004)
Ind	0.0001	0.0021 ***	0.0021 ***	0.0022 ***
	0.0001	(0.000)	(0.0006)	(0.0001)
GOV	0.0157	−0.0272 ***	0.0091	−0.0285 ***
	(0.0118)	(0.0041)	(0.0090)	(0.0042)
Inv	0.0072 ***	0.0055 ***	0.0112 ***	0.0046 ***
	(0.0005)	(0.0002)	(0.0008)	(0.0002)
Sobel Z	-	-	-	8.4370 ***
				(0.0031)
Constant	−0.7940 ***	−0.0866 ***	0.0065	−0.0872 ***
	(0.0550)	(0.0047)	(0.0090)	(0.0031)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	3653	3653	3653	3653
R^2	0.374	0.924	0.666	0.932

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$.

In summary, the mechanism test results in Tables 7–9 confirm that the enhancement of industrial chain resilience, ecological resilience, and talent agglomeration are three major important channels through which urban green-infrastructure investment improves sustainable urban economic development capabilities, further supporting the research Hypotheses H2, H3, and H4.

5.3. Spatial Effect Test

Initially, this study calculates a spatial economic and geographical nested matrix and employs the global Moran's I index to examine the spatial correlation between urban green-infrastructure investment and sustainable urban economic development levels. The results in Table 10 show that the Moran's I indices for both green-infrastructure investment and economic sustainable development levels are not zero, indicating significant spatial correlation. This means that urban green-infrastructure investment not only affects local economic sustainability but may also influence neighboring cities through spatial spillover effects.

Table 10. Global spatial autocorrelation test.

Year	Green-Infrastructure Investment Moran's I	Economic Resilience Moran's I
2010	0.2467	0.1039
2011	0.3614	0.1741
2012	0.2612	0.1279
2013	0.2871	0.0541
2014	0.2630	0.0744
2015	0.3012	0.1217
2016	0.2551	0.0278
2017	0.1957	0.1341
2018	0.1844	0.1596
2019	0.1630	0.1079
2020	0.1836	0.1217
2021	0.1917	0.0693
2022	0.1753	0.0942

To further explore the impact of urban green-infrastructure investment on sustainable urban economic development and its potential spatial spillover effects, this study draws on the research of Wang et al. and compares various econometric models. To effectively control for biases from time-series and individual heterogeneity and to accurately capture spatial interdependencies and spillovers, this study, following Arogundade et al. [87], adopts a spatial Durbin model with double fixed effects as the core analytical framework. This provides a more scientific and reliable empirical basis. Table 11 clearly presents the quantified results of the spatial spillover effects of urban green-infrastructure investment on sustainable urban economic development. As shown in Column (1) of Table 11, the spatial autoregressive coefficient is significantly positive at the 1% level. This indicates that in geographically adjacent cities, improvements in economic sustainability are not isolated but significantly interdependent. Thus, enhancements in one city's economic sustainability can positively promote that of neighboring cities, providing important theoretical support for regional economic coordination.

To further analyze the specific mechanisms through which urban green-infrastructure investment affects sustainable urban economic development, this study decomposes the overall impact into direct, indirect, and total effects. The indirect effect, which measures the impact on other cities through spatial spillovers, is a key indicator for testing the existence of spatial spillover effects. As shown in Column (3) of Table 11, the indirect effect is significantly positive at the 1% level, and the spatial autoregressive coefficient is also significantly positive at the 1% level. This strongly indicates that urban green-infrastructure investment not only positively affects the local city's economic sustainability but also significantly promotes that of neighboring cities through spatial spillovers, thereby verifying Hypothesis H5.

Table 11. Spatial autoregressive coefficient.

Variables	Main (1)	LR_Direct (2)	LR_Indirect (3)	LR_Total (4)
Score	0.1270 ***	0.0625 ***	0.0245 ***	0.1872 ***
	(0.0254)	(0.0121)	(0.0066)	(0.0177)
LnPop	0.0271 ***	0.0350 ***	0.0171 ***	0.0266 ***
	(0.0031)	(0.0024)	(0.0015)	(0.0014)
AvGDP	0.0067 ***	0.0061 ***	0.0057 ***	0.0082 ***
	(0.0003)	(0.0002)	(0.0004)	(0.0004)
Ind	0.0034 ***	0.0067 ***	0.0012 ***	0.0054 ***
	(0.0004)	(0.0001)	(0.0000)	(0.0001)
Gov	−0.0587 ***	−0.0121	−0.0296 ***	−0.0483 ***
	(0.0145)	(0.0092)	(0.0040)	(0.0091)
Inv	0.0061 ***	−0.1568 ***	0.0046 ***	0.0008
	(0.0012)	(0.0271)	(0.0006)	(0.0007)
Spatial Autoregressive Coefficient	0.7161 ***	-	-	-
	(0.0821)			
Sigma2_e	0.0104 ***	-	-	-
	(0.0018)			
Year	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes
N	3653	3653	3653	3653
R^2	0.316	0.316	0.316	0.316

Standard errors in parentheses, *** $p < 0.01$.

Drawing on real-world examples, the Yangtze River Delta region in China has established a green integrated development demonstration zone. This allows cities with advanced green development policies and investment experiences to more easily transfer their successful practices to neighboring cities. For example, after the successful implementation of electric buses and sponge city projects in some cities, these initiatives quickly spread to surrounding areas. This greatly improved the efficiency of green-infrastructure investment and the rationality and scientific nature of green-infrastructure construction, rapidly transforming the region into a world-class green demonstration zone [88]. It also significantly promoted the intelligent and green development of cities within the region and enhanced their economic resilience. However, fully leveraging the spatial spillover effects of green-infrastructure investment on urban economic resilience faces challenges such as inconsistent supporting policies and significant differences in development levels among cities, which hinder the application of advanced experiences from other cities. These issues require continuous optimization of policy measures [89].

Overall, the findings of this study—that urban green-infrastructure investment has spatial spillover effects on urban economic resilience—enrich the theoretical research on the relationship between green-infrastructure and sustainable urban economic development. They also provide important practical guidance for urban planners and policymakers in promoting regional coordinated development and enhancing urban economic sustainability.

The specific formulas and steps for the economic–geographic nested matrix are shown in Appendix C.

6. Heterogeneity Analysis

6.1. Urban Location Heterogeneity

The geographical location of a city has a significant impact on its economic development. Based on the geographical distribution of the sample cities, this study divides them into cities in the central and western regions and cities in the eastern region and conducts heterogeneity tests, respectively. The results are shown in Columns (1) and (2) of

Table 12. Column (1) shows that in the sample of cities in the central and western regions, the coefficient of Score is 0.1800, which is significant at the 1% level. However, Column (2) indicates that in the sample of cities in the eastern region, the coefficient of Score is 0.0405, which is significant at the 1% level. This suggests that the promoting effect of urban green-infrastructure investment on urban sustainable development levels is more pronounced in the central region of China than in the eastern region. The reasons may include the following: ① The industrial structure of the central and western regions is relatively simple, with lower technological interconnection and complexity and greater potential for development [90]. It is easier to promote economic transformation and upgrading, and the effect on enhancing sustainable development levels is more evident. ② Compared with cities in the eastern region, cities in the central and western regions, being located inland, have a market that is more reliant on domestic demand and is less affected by fluctuations in foreign markets. Under the impact of economic crises, the central and western regions are affected to a lesser extent than the eastern region and recover relatively faster. ③ Since the launch of environmental protection work in China, cities in the central and western regions, with fewer polluting enterprises and easier access to green energy such as photovoltaic and hydropower, have more advantageous opportunities for the development of green industries than cities in the eastern region [91]. Therefore, the effect of urban green-infrastructure investment on enhancing their sustainable development levels is more pronounced. In summary, the differences in industrial structure foundation, market supply-and-demand sources, and conditions for green industry development together lead to a more significant effect of urban green-infrastructure investment on enhancing the sustainable development levels of cities in the central and western regions.

Table 12. Heterogeneity analysis results (1).

Variables	(1) Central and Western Regions Cities	(2) Eastern Region Cities	(3) Resource-Based Cities	(4) Non-Resource-Based Cities
Score	0.1800 ***	0.0405 ***	0.178 ***	0.0665 ***
	(0.0189)	(0.0137)	(0.0274)	(0.0124)
LnPop	0.0195 ***	0.0365 ***	0.0160 ***	0.0331 ***
	(0.0012)	(0.0029)	(0.0012)	(0.0021)
AvGDP	0.0087 ***	0.0068 ***	0.0068 ***	0.0077 ***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Ind	0.0017 ***	0.0027 ***	0.0017 ***	0.0025 ***
	(0.0000)	(0.0001)	(0.0000)	(0.0001)
GOV	−0.0052	−0.0128	0.0005	−0.0126
	(0.0064)	(0.0091)	(0.0052)	(0.0083)
Inv	0.0074 ***	0.0060 ***	0.0040 ***	0.0061 ***
	(0.0004)	(0.0002)	(0.0006)	(0.0002)
Constant	−0.125 ***	−0.248 ***	−0.0943 ***	−0.2290 ***
	(0.0073)	(0.0173)	(0.0069)	(0.0131)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	2431	1222	1178	1422
R^2	0.542	0.633	0.621	0.484

Standard errors in parentheses, *** $p < 0.01$.

6.2. Urban Resource Endowment Heterogeneity

A city's resource endowment often determines its basic development status. Drawing on the research of Hu et al. [92], this study categorizes cities into resource-based and non-resource-based cities for separate empirical analyses. The results in Columns (3) and (4)

of Table 12 indicate that in cities with better resource endowments, green-infrastructure investment has a more significant impact on sustainable urban economic development. The possible reasons for this phenomenon are as follows: ① Cities with better resource endowments can leverage their advantages to achieve economic development earlier and have a stronger economic foundation [93]. This provides more sufficient financial support for green-infrastructure investment. ② Cities rich in resources such as water, forests, minerals, and clean air can use green-infrastructure investment to promote the rational use and protection of these resources. This enhances sustainable resource utilization and urban innovation, thereby boosting economic sustainability. ③ Cities with better resource endowments often have industrial structures dominated by heavy industries with higher pollution levels. Increased green-infrastructure investment can more significantly improve urban environmental quality and ecological resilience, injecting strong momentum into sustainable urban development.

6.3. Urbanization Level Heterogeneity

The level of urbanization in a city typically reflects its development stage and basic condition. In this paper, the proportion of urban household population to the total household population in a city is used to measure the level of urbanization. Cities with an urbanization rate lower than the average urbanization rate of all cities by one standard deviation in each year are selected as cities with a lower urbanization rate, while cities with an urbanization rate higher than the average by one standard deviation are considered as cities with a higher urbanization rate. Empirical analyses are then conducted separately for these two groups of cities. The results in Columns (1) and (2) of Table 13 indicate that in cities with a lower urbanization rate, the impact of green-infrastructure investment on urban sustainable development is more significant. The possible reasons for this phenomenon are as follows: First, cities with a lower urbanization rate are generally still in the development stage, with a greater demand for urban expansion and infrastructure construction [94]. Green-infrastructure investment can be more effectively integrated into urban planning and development, playing a greater economic and social role. Second, in cities with a lower urbanization rate, the urban household population is relatively small, creating a larger demand gap for urban residents. Green-infrastructure investment can promote the formation and development of related industries, directly create job opportunities, attract more labor to move into the city, and enhance the city's economic vitality and sustainable development capacity. Third, cities with a lower urbanization rate usually lag behind cities with a higher urbanization rate in terms of green and public facility construction. Investment in green infrastructure can improve the urban ecological environment, enhance the livability of the city, effectively improve the quality of life of residents [95], promote population inflow and economic development, and inject strong momentum into improving the level of urban sustainable development.

6.4. Urban Openness Level Heterogeneity

The level of openness of a city reflects its participation in the global market. In this paper, the proportion of a city's annual total import and export volume to its GDP in the same year is used to measure the city's level of openness. Cities with an openness level lower than the average openness level of all cities by one standard deviation in each year are selected as cities with a lower level of openness, while cities with an openness level higher than the average by one standard deviation are considered as cities with a higher level of openness. Empirical analyses are then conducted separately for these two groups of cities, with the results presented in Columns (3) and (4) of Table 13. According to the regression results, it is found that in cities with a higher level of openness, the positive

impact of green-infrastructure investment on urban sustainable development is more pronounced. The possible reasons are as follows: ① Cities with a higher level of openness are more likely to attract international cooperation projects, and the promotion of green-infrastructure investment through international technological exchanges is stronger [96], which enhances the efficiency and effectiveness of investment. ② Open cities generally enjoy better policy support and urban innovation capabilities, which can better promote the implementation of green-infrastructure investment and related policies and enhance the effect of green-infrastructure investment. ③ Cities with a higher level of openness are more strongly influenced by the mainstream international environmental protection ideas [97], and usually have higher environmental awareness and public participation within the city, which effectively promotes the implementation of green-infrastructure investment and the improvement of public acceptance, and enhances the positive impact of green-infrastructure investment on the level of sustainable development.

Table 13. Heterogeneity analysis results (2).

Variables	(1) Lower-Level-of-Urbanization Cities	(2) Higher-Level-of-Urbanization Cities	(3) Higher-Level-of-Openness Cities	(4) Lower-Level-of-Openness Cities
Score	0.2180 ***	0.0274	0.101 ***	−0.118 ***
	(0.0152)	(0.0167)	(0.0114)	(0.0197)
LnPop	0.0212 ***	0.0288 ***	0.0265 ***	0.0167 ***
	(0.001)	(0.0030)	(0.0016)	(0.0018)
AvGDP	0.00839 ***	0.0068 ***	0.00723 ***	0.0083 ***
	(0.0002)	(0.0003)	(0.0002)	(0.0003)
Ind	0.0017 ***	0.0035 ***	0.0023 ***	0.0018 ***
	(0.0000)	(0.0005)	(0.0001)	(0.0001)
GOV	0.0120 ***	−0.0582 ***	−0.0157 **	−0.0011
	(0.0043)	(0.0167)	(0.0067)	(0.0084)
Inv	0.0020 ***	0.0061 ***	0.0057 ***	0.0098 ***
	(0.0003)	(0.0003)	(0.0002)	(0.0004)
Constant	−0.1332 ***	−0.2271 ***	−0.1763 ***	−0.1071 ***
	(0.0063)	(0.0178)	(0.0010)	(0.0108)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	1178	1422	1517	1246
R^2	0.621	0.484	0.519	0.485

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$.

6.5. Urban Scale Heterogeneity

Previous research has found that urban scale has a strong interactive relationship with regional innovation and economic growth [98]. Therefore, it is necessary to examine the differences in effects across different urban scales. Following the research of Wang et al., this study classifies cities with a population of less than 5 million as medium and small cities, and those with a population of more than 5 million as large cities. Empirical analyses are conducted separately for these two groups. The results in Columns (1) and (2) of Table 14 show that in large cities, green infrastructure investment has a more significant impact on sustainable urban economic development. The possible reasons for this phenomenon are as follows: First, large cities typically have large populations and high population densities. Improvements in green infrastructure, such as increasing urban green spaces and optimizing sewage systems, generate more noticeable environmental benefits and have a more pronounced impact on urban green economic sustainability. Second, large cities, with their frequent economic activities and large-scale industries, consume a significant

amount of resources. Green-infrastructure investment helps improve resource utilization efficiency. For example, constructing advanced sewage treatment systems and recycled water facilities can effectively treat and reuse large amounts of wastewater, reducing dependence on freshwater resources and thus more significantly enhancing the city's ability to withstand natural disasters and other shocks. Third, large cities usually have more complex and diverse industrial structures with high inter-industry linkages. Green-infrastructure investment is more effective in promoting synergistic development among industries and in driving the formation of a highly integrated and complex economic model, thereby more effectively boosting urban economic resilience.

Table 14. Heterogeneity analysis results (3).

Variables	(1) Large-Sized Cities	(2) Medium- and Small-Sized Cities	(3) High-Levels-of-Government-Intervention Cities	(4) Insufficient-Levels-of-Government-Intervention Cities
Score	0.1120 ***	0.0014	0.1037 ***	0.0087
	(0.0152)	(0.0119)	(0.0025)	(0.0126)
LnPop	0.0212 ***	0.0211 ***	0.0233 ***	0.0155 ***
	(0.001)	(0.0028)	(0.0009)	(0.0018)
AvGDP	0.0045 ***	0.0158 ***	0.0051 ***	0.0074 ***
	(0.0002)	(0.0002)	(0.0002)	(0.0004)
Ind	0.0037 ***	0.0145 ***	0.0026 ***	0.0018 ***
	(0.0002)	(0.0004)	(0.0002)	(0.0041)
GOV	0.0174 ***	−0.0642 ***	−0.0119 **	−0.0058
	(0.0036)	(0.0177)	(0.0042)	(0.0062)
Inv	0.0022 ***	0.0053 ***	0.0066 ***	0.0175 ***
	(0.0003)	(0.0002)	(0.0002)	(0.0004)
Constant	−0.2091 ***	−0.2385 ***	−0.2041 ***	−0.1293 ***
	(0.0043)	(0.0097)	(0.0037)	(0.0046)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	286	3367	1703	1950
R^2	0.562	0.519	0.483	0.578

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$.

6.6. Government Intervention Heterogeneity

Since large-scale infrastructure investment often relies on unified planning and construction by the government, this study, following the research of Li et al. [99], uses the frequency of terms related to green infrastructure in city government work reports to measure the level of government intervention in green-infrastructure investment. Cities with a term frequency greater than one standard deviation above the mean are classified as having high government intervention, while those with a frequency less than one standard deviation below the mean are classified as having insufficient government intervention. Empirical analyses are conducted separately for these two groups, with the results shown in Columns (3) and (4) of Table 14. The regression results indicate that, in cities with higher levels of government intervention, green-infrastructure investment has a more pronounced positive effect on sustainable urban economic development. The possible reasons are as follows: First, cities with higher levels of government intervention can develop comprehensive and systematic plans for green infrastructure. By integrating green infrastructure construction with urban spatial layout, industrial planning, and population development, these cities enhance the benefits of green infrastructure for urban economic sustainability. Second, governments can allocate substantial public resources to green infrastructure projects. Therefore, cities with higher government intervention can better

utilize public power and financial capabilities to coordinate land, funding, and human resources, ensuring the smooth implementation of key green-infrastructure projects. Third, cities with higher government intervention have stronger regulatory capabilities. They can strictly monitor the construction and operation of green-infrastructure projects, effectively address issues such as misuse of funds, and ensure that the benefits of green-infrastructure investment are fully realized.

7. Robustness Tests

7.1. Addressing Endogeneity Issues

As research deepens, an increasing number of scholars have begun to focus on endogeneity issues [100]. First, to address endogeneity caused by correlation between explanatory variables and the error term, this study selects instrumental variables and employs two-stage least-squares (2SLS) regression. For the choice of instrumental variables, the following approaches are taken:

First, this study constructs a dummy variable, using whether a city is included in the key air pollution control zone as the instrumental variable Ins1. If a city is included in the key air pollution control zone, Ins1 takes a value of 1; otherwise, it takes a value of 0. On the one hand, being included in the key air pollution control zone implies that the city must enhance its focus on environmental protection and actively improve urban environmental quality through increased green-infrastructure investment, thus satisfying the relevance requirement of the instrumental variable. On the other hand, whether a city is included in the key air pollution control zone has a negligible impact on the current level of urban sustainable development, meeting the exogeneity condition of the instrumental variable. Columns (1) and (2) of Table 15 present the estimation results for Ins1. The first-stage 2SLS regression results show that the coefficient of Ins1 is 0.2021, which is significantly positive at the 1% level. This indicates that the selected instrumental variable is significantly positively correlated with the level of urban green-infrastructure investment. The second-stage estimation results show that the coefficient of Score is 0.5852, which is significantly positive at the 1% level, indicating robust study results. Additionally, the results of the weak instrument variable test show that the Kleibergen–Paap rk Wald F statistic significantly exceeds the critical value of 16.38 at the 5% significance level, passing the weak instrument variable test well. The p-values of the chi-squared (1) statistic are all less than 0.1, indicating that the Durbin–Wu–Hausman test cannot reject the null hypothesis that the instrumental variables are endogenous, meaning the instrumental variables are exogenous to the explained variable.

Second, considering that the number of employees in urban environmental protection (Env) is an important indicator reflecting the emphasis on urban green construction and has a clear positive correlation with urban green-infrastructure investment while having almost no direct correlation with sustainable urban economic development levels, this study, following Pierce et al. [101], introduces the number of employees (in ten thousand) in the urban environmental protection sector as the second instrumental variable (Ins2) for testing. The results are shown in Columns (3) and (4) of Table 15. The Wald F statistic exceeds the critical value of 16.38 at the 5% significance level, passing the weak instrument variable test. In these tests, the conclusions remain unchanged, and the positive promoting effect of urban green-infrastructure investment on sustainable urban economic development levels is robust.

Further, the entropy method used to calculate sustainable urban economic development levels and green-infrastructure investment data may introduce confounding information into the data, affecting the baseline regression results. Principal component analysis (PCA), as an effective dimensionality reduction technique, can extract key information

and reduce variable redundancy, thereby simplifying the model and reducing the risk of overfitting [102]. Additionally, PCA can eliminate the impact of outliers in individual variables on model results, enhancing model robustness [103]. Based on this, to avoid interference from potential multicollinearity in the original data, the study conducts a PCA. Figure 3 shows the decay of variables after dimensionality reduction, and the empirical results are presented in Table 16. The extracted principal components (pc1–pc6) all show that urban green-infrastructure investment has a significant impact on economic sustainable development levels, with the model demonstrating high explanatory power, further validating the robustness of the original model. After considering potential endogeneity issues, the conclusions remain unchanged, enhancing the credibility of the study results.

Table 15. Robustness tests (1).

Variables	(1) Score	(2) EcoRes	(3) Score	(4) EcoRes
Ins1	0.2021 ***	-	-	-
	(0.0514)			
Ins2	-	-	0.1960 ***	-
			0.0028	
Score	-	0.5852 ***	-	0.7680 ***
		(0.1595)		0.1237
LnPop	0.0073 ***	0.0123 ***	0.0030 **	0.0109 ***
	(0.0012)	(0.0016)	0.0013	0.0014
AvGDP	0.0021 ***	0.0049 ***	0.0032 ***	0.0044 ***
	(0.0005)	(0.0006)	0.0004	0.0007
Ind	0.0011 ***	0.0014 ***	0.0009 ***	0.0012 ***
	(0.0001)	(0.0002)	0.0001	0.0001
GOV	−0.0196	−0.0277 ***	0.0024	−0.0280 ***
	(0.0072)	(0.0083)	0.0062	0.0083
InvInn	0.0108 ***	0.0007	0.0089 ***	−0.0016 ***
	(0.0008)	(0.0020)	0.0008	0.0017
Constant	−0.0736 ***	−0.4859 ***	0.0575 ***	−0.0389 **
	(0.0106)	(0.0000)	0.0091	0.0119
N	3653	3653	3653	3653
R^2	0.807	0.898	0.822	0.861
Chi-squared (1)	23.527	-	18.795	-
	(0.125)		(0.349)	
Kleibergen–Paap rk Wald F Value	16.7942	-	49.4559	-
	(16.38)		(16.38)	

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$.

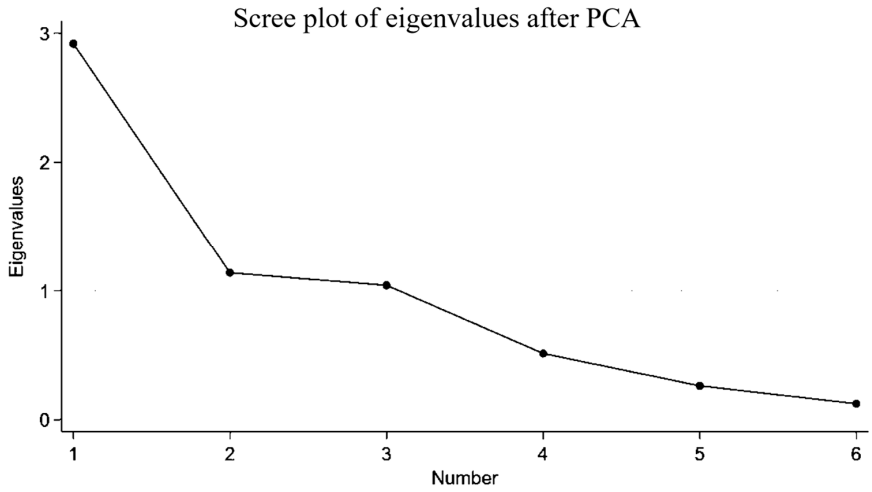

Figure 3. Dimensionality reduction diagram of core variables.

Table 16. Robustness tests (2).

Variables	(1) EcoRes
pc1	0.0382 ***
	(0.0002)
pc2	0.0058 ***
	(0.0003)
pc3	0.0032 ***
	(0.0003)
pc4	0.0019 ***
	(0.0005)
pc5	0.0051 ***
	(0.0006)
pc6	0.0033 ***
	(0.0009)
Constant	0.1250 ***
	(0.0003)
N	3080
R^2	0.927

Standard errors in parentheses, *** $p < 0.01$.

7.2. Adding Control Variables

Previous studies have indicated that the financing level of a city exerts a significant influence on its investment capacity. Generally, cities with higher financing levels and more active financing markets tend to have larger investment amounts in various types of infrastructure. Therefore, it is necessary for this study to take into account the financing level of cities. In this paper, the basic financing level of a city is measured by the ratio of the annual total deposits and loans of financing institutions (in CNY ten thousand) to the city's annual GDP (in CNY ten thousand), and the Fin variable is included as a control variable. Moreover, the accelerated advent of the intelligent and technological era will amplify the agglomeration effect of talent [104]. Thus, it is essential for the study to consider the initial conditions of talent agglomeration. Since the talent level of a city is constrained by the level of education, which is usually reflected by the number of education practitioners, this paper also includes the number of education practitioners in the city (in ten thousand people) as the Tech variable in the empirical model for control. The results in Column (1) of Table 17 show that the coefficient of *Score* is 0.4552, which is significant at the 1% level. This indicates that even after controlling for the impact of urban financing level and urban education level, urban green-infrastructure investment still has a significant positive effect on the level of urban sustainable development.

7.3. High-Dimensional Fixed-Effects Test

Taking into account the unobservable heterogeneity in economic development and social environment across Chinese provinces, including cultural differences, policy environments, and historical backgrounds, which may influence the results of empirical analysis, this paper conducts a high-dimensional fixed-effects test after controlling for the province to which the city belongs. The results are presented in Column (2) of Table 17. At this juncture, the coefficient of Score stands at 0.2341, which is significantly positive at the 1% level. This finding indicates that, after excluding interprovincial differences, urban green-infrastructure investment still exerts a significant positive impact on the enhancement of sustainable urban development. Thus, the research conclusion remains robust.

Table 17. Robustness tests (3).

Variables	(1) EcoRes	(2) EcoRes
Score	0.4552 ***	0.2341 ***
	(0.0172)	(0.0101)
LnPop	0.0125 ***	0.0153 ***
	(0.0041)	(0.0012)
AvGDP	0.0051 ***	0.0076 ***
	(0.000)	(0.000)
Ind	0.0021 ***	0.0023 ***
	(0.0000)	(0.0000)
GOV	−0.0132 ***	−0.0314 ***
	(0.0050)	(0.0041)
Inv	0.0042 ***	0.0022 ***
	(0.0001)	(0.0000)
Fin	0.0020 ***	-
	(0.0000)	
Tech	0.0082 ***	-
	(0.000)	
Constant	−0.0801 ***	−0.0861 ***
	(0.0220)	(0.0041)
City	Yes	Yes
Year	Yes	Yes
N	3653	3653
R^2	0.877	0.897

Standard errors in parentheses, *** $p < 0.01$.

7.4. Exclusion of Data from Anomalous Years

In 2020, China and the rest of the world were severely impacted by the COVID-19 pandemic, which had a significant influence on economic and social development across regions. Therefore, it is necessary to address the interference caused by the data from 2020. Following the approach of Zucaro et al. [105], after excluding the sample data from 2020, the empirical results are shown in Column (1) of Table 18, where the coefficient of Score is 0.1594 and is significantly positive at the 1% level. Thus, even after removing the data from this anomalous year, urban green-infrastructure investment still significantly enhances the level of urban sustainable development, maintaining the robustness of the research conclusion.

7.5. Mitigation of Outlier Interference

To avoid the interference of outliers in the sample on the research results, this study, in line with Kolditz et al. [106], applies a two-sided 1% winsorization and trimming process to continuous variables. The results are presented in Columns (2) and (3) of Table 18. In both samples, the coefficients for Score are 0.4661 and 0.5620, respectively, both significantly positive at the 1% level. This indicates that, even after eliminating the influence of extreme values, urban green-infrastructure investment still significantly promotes the enhancement of urban sustainable development levels. The research conclusion remains unchanged in both the winsorized and trimmed samples, further validating the robustness of the results.

7.6. Lagged Effect Test

As an economic investment, urban green-infrastructure investment may exert a lagged effect on the sustainable development capacity of a city. From the perspective of project planning and construction cycles, the complexity of planning leads to difficulties in coordinating across multiple fields and departments. The differing interests and objectives

of various departments can prolong the planning period. Moreover, the construction phase is lengthy; for instance, large-scale green buildings and ecological parks typically take several years from initiation to operation, making it challenging to swiftly bolster sustainable development capacity. Therefore, this paper conducts a lagged-effect test, examining the situation of urban green-infrastructure investment with a lag of one and two periods, respectively.

Table 18. Robustness tests (4).

Variables	(1) Excluding Data from 2020	(2) Winsorized Regression	(3) Truncated Regression
Score	0.656 ***	0.4661 ***	0.5620 ***
	(0.0182)	(0.0170)	(0.0172)
LnPop	0.0321 ***	0.0261 ***	0.0352 ***
	(0.0041)	(0.0030)	(0.0032)
AvGDP	0.0055 ***	0.0080 ***	0.0070 ***
	(0.0001)	(0.0001)	(0.0001)
Ind	0.0027 ***	0.0022 ***	0.0021 ***
	(0.0003)	(0.0000)	(0.0000)
GOV	−0.0031	0.0365 ***	0.0192 ***
	(0.0055)	(0.0051)	(0.0050)
Inv	0.0050 ***	0.0022 ***	0.0030 ***
	(0.0000)	(0.0000)	(0.0000)
Constant	−0.2036 ***	−0.1651 ***	−0.2212 ***
	(0.0242)	(0.0190)	(0.0210)
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	3372	3653	3287
R^2	0.841	0.876	0.858

Standard errors in parentheses, *** $p < 0.01$.

According to the test results in Table 19, after lagging the situation of urban green-infrastructure investment by one and two periods, the investment still significantly and positively affects the level of urban sustainable development at the 1% significance level. This indicates that even when considering the lagged impact of investment, it can still be concluded that urban green-infrastructure investment positively promotes the enhancement of urban sustainable development.

Table 19. Robustness tests (5).

Variables	(1) EcoRes	(2) EcoRes
L.Score	0.6562 ***	-
	(0.0181)	
L2.Score	-	0.6442 ***
		(0.0203)
LnPop	0.0417 ***	0.0446 ***
	(0.0041)	(0.0044)
AvGDP	0.0043 ***	0.0041 ***
	(0.0001)	(0.0000)
Ind	0.0022 ***	0.0036 ***
	(0.0000)	(0.0000)
GOV	0.0091	0.0017
	(0.0064)	(0.0062)

Table 19. *Cont.*

Variables	(1) EcoRes	(2) EcoRes
Inv	0.0067 ***	0.0064 ***
	(0.0000)	(0.0002)
Constant	−0.2581 ***	−0.2667 ***
	(0.0244)	(0.0253)
N	3372	3091
R^2	0.836	0.818

Standard errors in parentheses, *** $p < 0.01$.

8. Discussion

8.1. Discussion on the Role of Urban Green-Infrastructure Investment in the Sustainable Development of Urban Economy

Research on the relationship between urban green-infrastructure investment and urban sustainable development has made certain progress. Regarding the impact effect, scholars have generally focused on the role of urban green-infrastructure investment in enhancing the economic recovery and risk-resistance capabilities of cities. Zeng et al. verified the significant positive effect of green-infrastructure investment on urban sustainable development through a panel data model, proving that the process of green-infrastructure investment can significantly enhance a city's recovery and adaptability when facing external shocks [35]. This conclusion provides important theoretical support for understanding the role of green-infrastructure investment in improving urban sustainable development. Nie et al. found that green-infrastructure investment mainly relies on multiple driving mechanisms, such as technology innovation and industrial collaborative innovation, by examining its impact on urban technological innovation [36]. Liu et al. further revealed that green-infrastructure investment can effectively promote urban policy support and collaborative governance, enabling cities to obtain more policy resources and thus promote sustainable development [37]. Wang et al. found that green-infrastructure investment significantly promotes urban sustainable development by improving the urban ecological environment and enhancing resource utilization efficiency through research on multiple US cities [38]. Lv et al. found that green-infrastructure investment and urban sustainable development levels show a "U"-shaped dynamic characteristic of first inhibition and then promotion in their research on Chinese cities [39]. This conclusion was further confirmed in the follow-up research by Wang et al. [40], providing an important theoretical basis for understanding the dynamic relationship between green-infrastructure investment and sustainable development levels.

With the increasing impact of global economic turbulence and external instability, exploring ways to enhance urban sustainable development capabilities has become more urgent. Urban green-infrastructure investment, as an important investment direction for improving urban green economic development and influencing economic trends, provides a new development path for enhancing urban sustainable development. Against this backdrop, existing research has thoroughly explored the impact of urban economic activities on sustainable development. In terms of impact effects, some scholars have verified the role of green-infrastructure investment in enhancing a city's recovery and adaptability when facing external shocks [35]. Liu et al.'s research also confirmed the objective role of urban green-infrastructure investment in promoting urban policy development and sustainable development [37]. This study also examines the impact of urban green-infrastructure investment on urban sustainable development. The empirical results show that urban

green-infrastructure investment can increase the level of urban sustainable development by an average of 0.059 units, further confirming the findings of existing research.

8.2. Discussion on the Mechanisms of Urban Green-Infrastructure Investment on Urban Economic Sustainable Development

In terms of mechanisms, Nie et al. focused on the innovation enhancement brought about by urban green-infrastructure investment [36], while Wang et al. identified industrial structure upgrading as a key pathway for improving sustainable urban economic development [38]. Li et al. explored the synergistic relationship between talent agglomeration and urban green-infrastructure investment [107]. The results of this study indicate that urban green-infrastructure investment can promote sustainable urban economic development by enhancing industrial chain resilience, improving environmental resilience, and fostering talent agglomeration. First, in enhancing industrial chain resilience, urban green-infrastructure investment can ensure the stability of resource supplies such as water through the construction of reservoirs and urban greening. These investments also attract green industries, promoting industrial collaboration and innovation, thereby strengthening the industrial chain. This resilience significantly boosts the city's ability to withstand shocks and supports long-term, stable development. Second, in improving environmental resilience, increased green-infrastructure investment supports the construction of flood- and wildfire-prevention infrastructure. It also funds the establishment of more ecological reserves and the protection of biodiversity. This enhances the resilience of urban ecosystems, reduces the impact of issues like invasive species and urban flooding, and positively affects the urban environment. Improved environmental resilience ensures ecological security, sustainable resource use, and economic sustainability. Third, in terms of talent agglomeration, green infrastructure creates a livable urban environment. Research shows that cities with high environmental quality are more attractive to talent. People prefer to live and work in cities with clean air and pleasant climates. Green infrastructure also drives the development of green industries, creating job opportunities for green tech talent and enhancing the city's appeal. Talent is the core driver of innovation. The concentration of high-end talent can lead to new technologies, products, and business models, accelerating industrial upgrading and boosting economic competitiveness. Talent agglomeration also stimulates consumption and the prosperity of related industries, creating more jobs and promoting economic circulation. Additionally, it fosters cultural exchange and integration, enhancing the city's openness and cultural soft power, attracting global resources, and strengthening international influence, thereby comprehensively promoting sustainable urban economic development.

Since the previous analysis focused on individual mechanisms, this study further examines the potential interactions between these mechanisms using a chain mediation model, constructed as follows:

$$\text{Mediator2}_{kt} = \text{ſ}_{0} + \text{ſ}_{1}\,\text{Score}_{kt} + \text{ſ}_{2}\,\text{Controls}_{kt} + \zeta_{k} + \delta_{t} + \mu_{kt} \quad (2)$$

$$\text{Mediator1}_{kt} = \phi_{0} + \phi_{1}\,\text{Mediator2}_{kt} + \phi_{2}\,\text{Score}_{kt} + \phi_{3}\,\text{Controls}_{kt} + \zeta_{k} + \delta_{t} + \varepsilon_{kt} \quad (3)$$

$$\text{Ecores}_{kt} = \gamma_{0} + \gamma_{1}\,\text{Score}_{kt} + \gamma_{2}\,\text{Mediator1}_{kt} + \gamma_{3}\,\text{Controls}_{kt} + \zeta_{k} + \delta_{t} + \varepsilon_{kt} \quad (4)$$

In Models (2), (3), and (4), if ſ_{1}, ϕ_{1}, γ_{1}, and γ_{2} are all significant, then the second mechanism variable interacts with the first mechanism variable. The explanatory variable first affects Mechanism Variable 1, which then affects Mechanism Variable 2. Through the combined influence of Mechanism 1 and Mechanism 2, the dependent variable is ultimately affected.

Based on Models (2)–(4), this study also introduces interaction terms of the mechanism variables into Model (1) to consider the interaction effects of the two chain mediation mechanisms on the dependent variable. Additionally, this study employs the Bootstrap estimation method to conduct a robustness test of the chain mediation effects.

Finally, through a series of empirical tests, this study finds significant chain mediation and interaction effects between environmental resilience and industrial chain resilience, as well as between talent agglomeration and environmental resilience. Although there is no direct chain mediation effect between talent agglomeration and industrial chain resilience, an indirect mediation effect can be inferred through the other two chain mediation effects. When their interaction term is included in the baseline regression model, a strong interaction effect is observed, with an interaction coefficient of 0.432, which is significant at the 1% level and has a positive impact on sustainable urban economic development.

The interaction results between environmental resilience and industrial chain resilience are shown in Table 20. According to the test results in Table 20, urban green-infrastructure investment has a significantly positive effect on environmental resilience at the 1% significance level. In Column (2), environmental resilience has a significantly positive effect on the industrial chain resilience mechanism variable at the 1% significance level. In Column (3), the industrial chain resilience mechanism variable has a significantly positive effect on sustainable urban economic development at the 1% significance level. This indicates that environmental resilience and industrial chain resilience jointly promote urban economic development. Moreover, the Bootstrap-estimated confidence interval does not include zero, confirming the robustness of this chain mediation effect. Finally, in Column (4), the interaction term between the two mechanisms has a significantly positive effect on sustainable urban economic development at the 1% significance level, verifying that the interaction between the two mechanisms promotes sustainable urban economic development.

Table 20. Mechanism synergy test (1).

Variables	**GTFP→IndRes**			
	TalGath	**IndRes**	**Score**	**Score**
	(1)	**(2)**	**(3)**	**(4)**
Score	0.9142 ***	0.5165 ***	0.6469 ***	0.5286 ***
	(0.0301)	(0.1192)	(0.0174)	(0.0183)
LnPop	0.1024 ***	−0.0260	0.0375 ***	0.0190 ***
	(0.0071)	(0.0251)	(0.0042)	(0.0041)
AvGDP	0.0000	0.0022 **	0.0053 ***	0.0055 ***
	(0.0000)	(0.0015)	(0.0002)	(0.0007)
Ind	0.0001	0.0014 ***	0.0026 ***	0.0023 ***
	(0.0002)	(0.0000)	(0.0004)	(0.0002)
GOV	0.0217 **	−0.0687 **	0.0033	−0.0000
	(0.0083)	(0.0296)	(0.0057)	(0.0050)
Inv	0.0084 ***	0.0007	0.0051 ***	0.0044 ***
	(0.0006)	(0.0024)	(0.0002)	(0.0003)
GTFP		0.4216 ***		
		(0.0651)		
IndRes			0.0168 ***	
			(0.0034)	
Constant	−0.6462 ***	0.424 ***	−0.2396 ***	−0.1214 ***
	(0.0401)	(0.144)	(0.0213)	(0.0231)

Table 20. *Cont.*

Variables	GTFP→IndRes			
	TalGath (1)	IndRes (2)	Score (3)	Score (4)
Interaction1				0.2056 ***
				(0.0117)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Bootstrap-Z	3.01			
	(0.004~0.019)			
N	3653	3653	3653	3653
R^2	0.514	0.437	0.848	0.863

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$.

Similarly, in the chain mediation mechanism test between talent agglomeration and urban environmental resilience, the results in Column (1) of Table 21 show that urban green-infrastructure investment has a significantly positive effect on the talent agglomeration variable at the 1% significance level. In Column (2), the talent agglomeration variable has a significantly positive effect on the environmental resilience mechanism variable at the 1% significance level. In Column (3), the environmental resilience mechanism variable has a significantly positive effect on sustainable urban economic development at the 1% significance level. The Bootstrap-estimated confidence interval does not include zero, indicating that there is a chain mediation effect between talent agglomeration and environmental resilience. Additionally, in Column (4), the interaction term between the two mechanisms has a significantly positive effect on sustainable urban economic development at the 1% significance level, confirming that the interaction between the two mechanisms promotes sustainable urban economic development.

Finally, based on the above two studies, it can be found that in the impact of green-infrastructure investment on sustainable urban economic development, a chain mediation effect is formed from talent agglomeration to urban environmental resilience and then to urban industrial chain resilience. There are chain mediation effects between talent agglomeration and urban environmental resilience, as well as between urban environmental resilience and urban industrial chain resilience, forming a complete chain mechanism effect.

Further, given the differences in location and type among cities, it is essential to analyze the specific manifestations of each mechanism under different urban conditions. Building on the previous research, this study conducts a more detailed mechanism analysis based on two fundamental urban differences: geographical location and city size. Cities are divided into eastern region cities and central and western region cities based on location, and into large cities (population over 5 million) and medium and small cities based on size. The regression results for the three mechanisms are shown in Tables 22–24, respectively. The data analysis reveals that the effects of urban green-infrastructure investment on enhancing industrial chain resilience and talent agglomeration are more pronounced in cities located in the central and western regions and in smaller cities. The possible reasons are as follows: ① The farther a city is from the eastern coastal region and the smaller its size, the lower its economic development level and degree of modernization tend to be. Such cities have a higher demand for capital and talent, making investment more impactful for their economic development. ② Smaller cities, with fewer initial talent numbers, are more likely to see significant talent attraction from green-infrastructure investment. Talent agglomeration plays a more prominent role in enhancing economic resilience through technological innovation and industrial upgrading. In contrast, the effect of urban green-infrastructure investment on improving environmental resilience is more evident in cities located in the

eastern region and larger cities. The possible reasons are as follows: ① Eastern coastal cities and larger cities generally have better economic foundations and more concentrated industrial activities, leading to more pronounced environmental degradation due to human activities. Green-infrastructure investment can more effectively improve environmental conditions in these cities, resulting in a more noticeable impact on environmental resilience. ② Cities with higher economic levels typically have residents with greater demands for environmental quality and higher attention to environmental protection. These cities place more emphasis on green-infrastructure investment to improve ecological conditions, thereby enhancing environmental resilience.

Table 21. Mechanism synergy test (2).

Variables	TalGath (1)	TalGath→IndRes IndRes (2)	TalGath→IndRes Score (3)	Score (4)
Score	0.1364 ***	0.6583 ***	0.6462 ***	0.5778 ***
	(0.0072)	(0.0295)	(0.0173)	(0.0172)
LnPop	0.0133 ***	0.0796 ***	0.0377 ***	0.0369 ***
	(0.0021)	(0.0061)	(0.0041)	(0.0044)
AvGDP	0.0005 **	0.0000	0.0058 ***	0.0052 ***
	(0.0003)	(0.0000)	(0.0006)	(0.0004)
Ind	−0.0001 ***	0.0001 ***	0.0024 ***	0.0027 ***
	(0.0000)	(0.0000)	(0.0001)	(0.0003)
GOV	0.0047 **	0.0121	0.0032	−0.0007
	(0.0022)	(0.0079)	(0.0055)	(0.0054)
Inv	0.0029 ***	0.0041 ***	0.0057 ***	0.0023 ***
	(0.0003)	(0.0002)	(0.0002)	(0.0005)
IndRes		1.8721 ***		
		(0.0733)		
TalGath			0.0168 ***	
			(0.0039)	
Constant	−0.0622 ***	−0.5316 ***	−0.2390 ***	−0.2232 ***
	(0.0097)	(0.0368)	(0.0233)	(0.0227)
Interaction1				0.4091 ***
				(0.0113)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Bootstrap-Z		4.65		
		(0.006~0.015)		
N	3653	3653	3653	3653
R^2	0.471	0.606	0.848	0.860

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$.

Table 22. Heterogeneity test of industrial chain resilience mechanism.

Variables	(1) Eastern Region Cities	(2) Central and Western Region Cities	(3) Large-Sized Cities	(4) Medium- and Small-Sized Cities
Score	0.2444 ***	0.3064 ***	0.1532 ***	0.2546 ***
	(0.0079)	(0.0149)	(0.0130)	(0.0102)
LnPop	0.0273 ***	0.0178 ***	0.0216 ***	0.0191 ***
	(0.0027)	(0.0013)	(0.0012)	(0.0028)
AvGDP	0.0054 ***	0.0081 ***	0.0082 ***	0.0052 ***
	(0.0002)	(0.0002)	(0.0002)	(0.0003)

Table 22. *Cont.*

Variables	(1) Eastern Region Cities	(2) Central and Western Region Cities	(3) Large-Sized Cities	(4) Medium- and Small-Sized Cities
Ind	0.0024 ***	0.0016 ***	0.0017 ***	0.0031 ***
	(0.0001)	(0.0000)	(0.0000)	(0.0001)
GOV	−0.0154 **	−0.0049	0.0161 ***	−0.0691 ***
	(0.0067)	(0.0066)	(0.0046)	(0.0140)
Inv	0.0042 ***	0.0072 ***	0.0028 ***	0.0045 ***
	(0.0002)	(0.0004)	(0.0003)	(0.0002)
Constant	−0.1745 ***	−0.1087 ***	−0.1310 ***	−0.1463 ***
	(0.0159)	(0.0075)	(0.0069)	(0.0166)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	1222	2431	286	3367
R^2	0.906	0.930	0.841	0.836

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$.

Table 23. Heterogeneity test of environmental resilience mechanisms.

Variables	(1) Eastern Region Cities	(2) Central and Western Region Cities	(3) Large-Sized Cities	(4) Medium- and Small-Sized Cities
Score	0.0337 ***	0.0245 ***	0.0411 ***	0.0021
	(0.0032)	(0.0014)	(0.0053)	(0.0056)
LnPop	0.00627 ***	0.0086 ***	0.0438 ***	0.0220 ***
	(0.0003)	(0.0002)	(0.0036)	(0.0016)
AvGDP	0.0028 ***	0.0017 ***	0.0059 ***	0.0098 ***
	(0.0001)	(0.0000)	(0.0003)	(0.0003)
Ind	−0.0079	0.0092 *	0.0028 ***	0.0016 ***
	(0.0116)	(0.0053)	(0.0001)	(0.0001)
GOV	0.0062 ***	0.0017 ***	−0.0085	0.0033
	(0.0003)	(0.0003)	(0.0098)	(0.0078)
Inv	0.0475 ***	0.0022	0.0060 ***	0.0077 ***
	(0.0019)	(0.0081)	(0.0003)	(0.0005)
Constant	−0.2431 ***	−0.1490 ***	−0.3041 ***	−0.1376 ***
	(0.0189)	(0.0084)	(0.0216)	(0.0097)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	1222	2431	286	3367
R^2	0.833	0.764	0.895	0.813

Standard errors in parentheses, *** $p < 0.01$, * $p < 0.1$.

Table 24. Heterogeneity test of talent agglomeration mechanism.

Variables	(1) Eastern Regions Cities	(2) Central and Western Regions Cities	(3) Large-Sized Cities	(4) Medium- and Small-Sized Cities
Score	0.3081 ***	0.6194 ***	0.2412 ***	0.5456 ***
	(0.0260)	(0.0419)	(0.0299)	(0.0389)
LnPop	0.0335 ***	0.0175 ***	0.0251 ***	0.0197 ***
	(0.0032)	(0.0014)	(0.0035)	(0.0011)
AvGDP	0.0069 ***	0.0092 ***	0.0071 ***	0.0085 ***
	(0.0002)	(0.0002)	(0.0003)	(0.0006)

Table 24. *Cont.*

Variables	(1) Eastern Regions Cities	(2) Central and Western Regions Cities	(3) Large-Sized Cities	(4) Medium- and Small-Sized Cities
Ind	0.0026 ***	0.0017 ***	0.0035 ***	0.0018 ***
	(0.0001)	(0.0001)	(0.0002)	(0.0000)
GOV	−0.0142	−0.0064	−0.0747 ***	0.0112 ***
	(0.0088)	(0.0067)	(0.0178)	(0.0043)
Inv	0.0042 ***	0.0035 ***	0.0045 ***	0.0010 ***
	(0.0003)	(0.0006)	(0.0004)	(0.0003)
Constant	−0.2281***	−0.1153 ***	−0.2030 ***	−0.1254 ***
	(0.0192)	(0.0085)	(0.0205)	(0.0067)
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	1222	2431	286	3367
R^2	0.851	0.772	0.908	0.872

Standard errors in parentheses, *** $p < 0.01$.

8.3. Research Contributions and Limitations

Building on the existing literature, this study innovates in both perspective and content. In terms of perspective, existing research has given relatively limited attention to the impact of urban green-infrastructure investment. However, with the increasing amount of green-infrastructure investment and the gradual implementation of projects, the investment has shown a strong ability to improve economic sustainability. Therefore, this study focuses on the development journey of 281 Chinese cities over 13 years, elucidating the role of green-infrastructure investment in urban economic sustainability through concrete data. In terms of content, although the existing literature has explored the mechanisms of urban green-infrastructure investment at the macro level, such as enhancing urban green innovation capabilities and promoting talent "suction" effects [108], this study further investigates these mechanisms. The mechanism test results indicate that regional integration can enhance urban economic sustainability by strengthening industrial chain resilience, improving urban ecological resilience, and promoting talent agglomeration. Additionally, while Zeng et al.'s research [35] has focused on sustainable urban economic development, their study only examined a single element of urban economic development, resulting in a relatively narrow measurement of urban economic sustainability. In contrast, this paper comprehensively assesses urban economic sustainability from three dimensions: resistance and recovery capacity, adjustment and adaptation capacity, and development transformation capacity, enhancing the objectivity and comprehensiveness of the research. Third, although some studies have explored the impact of urban green-infrastructure investment on urban economic sustainability, they have not paid attention to the spatial spillover effects of this impact. In contrast, this study examines this aspect and finds that urban green-infrastructure investment has a positive spatial spillover effect on enhancing economic sustainability. Moreover, while existing research has explored the heterogeneity of green-infrastructure investment effects by focusing on urban location and resource endowment differences, it has paid less attention to differences in urbanization rates and levels of urban openness. This study examines these dimensions and finds that urban green-infrastructure investment has a more significant impact in cities in the central and western regions, cities with better resource endowments, cities with lower urbanization rates, and cities with higher levels of openness.

In summary, this study not only verifies the positive impact of urban green-infrastructure investment on urban economic sustainability but also achieves significant

breakthroughs in perspective and content compared to the existing literature, providing insights and references for future multi-perspective analyses of the effects of urban green-infrastructure investment. However, this study also has certain limitations, mainly including: ① Limitations in variable selection: There may be important variables such as natural geographical conditions and historical and cultural backgrounds that are not included in the model. Generally speaking, cities with better natural geographical conditions are less affected by natural disasters such as earthquakes and floods and have more stable economies. Cities with a conservative cultural atmosphere, a higher aversion to risky investments, or a preference for internal economic development models are less affected by external environmental shocks and have more stable economic operations. These factors have not been fully considered in this study. ② Limitations in indicator measurement: This study mainly examines urban green-infrastructure investment from three aspects: urban sewage discharge capacity, public transportation construction level, and urban greening level, which may not fully capture the level of urban green-infrastructure investment. The main reasons are as follows: measuring green investment in urban sewage discharge only by sewage volume and pipeline length may neglect investments in sewage treatment technology and capacity improvement; considering only the construction of taxis and buses may lead to a lack of measurement of investments in urban roads and green transportation networks; and green space area and greening rates cannot fully reflect investments in urban afforestation and reforestation. The current indicators still have certain limitations.

Based on the above analysis, future research can improve this study in the following aspects: ① Expand the sample coverage: increase the number of city samples from different countries and extend the research timespan to more comprehensively reveal the long-term impact and dynamic evolution of urban green-infrastructure investment. ② Enrich the variable and indicator system: incorporate more factors that may affect urban economic sustainability, such as socio-cultural and policy institutional factors, to more comprehensively capture the complex connotations of urban economic sustainability. ③ Conduct cross-country comparative studies: compare differences in green-infrastructure investment and economic sustainability among cities in different countries to explore the underlying mechanisms and patterns, providing more universal theoretical guidance and practical references for global urban economic sustainability.

9. Conclusions and Recommendations

In today's era of economic globalization, the role of urban green-infrastructure investment in enhancing economic sustainable development capabilities is becoming increasingly prominent. This study, based on panel data from 281 prefecture-level cities in China from 2010 to 2022, employs an empirical model to thoroughly explore the impact of urban green-infrastructure investment on sustainable urban economic development levels as well as its underlying mechanisms. The results show that (1) Urban green-infrastructure investment significantly promotes the improvement of sustainable urban economic development levels. This conclusion remains robust after a series of stability tests, including propensity score matching (PSM), instrumental variable testing, and the addition of new control variables. (2) The mechanism test results indicate that enhancing industrial chain resilience, ecological environment resilience, and talent agglomeration are key pathways through which green-infrastructure investment optimizes sustainable urban economic development. (3) There is significant heterogeneity in the response of cities with different regions, resource endowments, levels of openness, city sizes, and degrees of government intervention to the impact of regional integration policies. In particular, cities in the central and western regions, resource-based cities, cities with higher urbanization rates, and cities with higher levels

of openness, larger scales, and greater government intervention are more sensitive to the positive effects of green-infrastructure investment on economic sustainability.

Based on the above research conclusions, this paper proposes the following policy recommendations:

Firstly, focus on the city's location and take the initiative in urban economic construction. The positive effect of urban green-infrastructure investment on sustainable urban economic development is more evident in cities in the central and western regions. Cities in these areas should actively plan green-infrastructure investment projects, increase the proportion of green-infrastructure investment, and shift fiscal spending and social resources towards green infrastructure projects. This will truly enhance the role of green-infrastructure investment in boosting urban economic sustainability.

Secondly, leverage resource advantages and explore new models for resource utilization. Resource-based cities show a more pronounced effect of green-infrastructure investment on economic sustainability. These cities should proactively improve the efficiency of green-infrastructure investment funds and increase support for emerging industries with higher resource utilization rates, such as wind power, nuclear power, and water-saving industries. By refining policy systems, they can accelerate the development of clean energy and eco-friendly transportation. At the same time, efforts should be made to transform traditional energy-intensive and high-pollution industries to enhance overall resource efficiency in the industrial chain and promote stable urban economic development.

Thirdly, pay attention to the needs of the people and promote the construction of livable urban environments. Cities with higher urbanization rates have denser urban populations and higher environmental demands. These cities should actively use green-infrastructure investment to explore green economic development models and reduce the impact of human activities on the ecological environment. They should continue to promote reforestation and grassland restoration, accelerate the establishment of nature reserves, and allow natural ecosystems to play a more important role in environmental evolution. They should also advance green production technologies, promote the development of green technologies, and guide industries towards greener practices. This will help build eco-friendly cities that meet the environmental needs of urban residents. Cities with lower urbanization rates should also base their development on actual conditions, ensure a solid ecological foundation, leverage the environmental protection advantages of small cities, and develop unique ecological models to enhance urban economic sustainability.

Fourthly, enhance the level of openness and promote long-term stable economic development. Cities with higher levels of openness show a more significant impact of green-infrastructure investment on economic sustainability. These cities should continue to expand their openness, implement national policies, and combine "bringing in" with "going global" to improve the exchange of goods, culture, and other elements with the outside world. By establishing supportive policies, they can facilitate the exchange of advanced ideas and technologies, promote technological progress and industrial upgrading, optimize the economic structure, and enhance the stability and development capabilities of the urban economy.

Fifthly, increase the attention level of city governments and play a guiding and regulatory role. Government macro-control and overall guidance have a significant impact on the use of green-infrastructure investment funds and urban economic development. Local governments should continuously strengthen their guidance and attention to green-infrastructure investment projects, ensure the implementation and efficient use of funds, and monitor their usage. They should also establish and improve relevant policies and regulations to encourage green infrastructure construction, uncover the overall anti-interference

capabilities of the economic system, and inject strong momentum into the long-term stable development of the urban economy.

Author Contributions: Conceptualization, S.C. and Z.W.; Methodology, S.C. and D.D.; Software, D.D.; Data curation, Z.W.; Writing—original draft, S.C. and Z.W.; Writing—review & editing, Q.K.; Funding acquisition, Q.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the China College Students' Innovation and Entrepreneurship Training Program (research on "Turning "Carbon" into "Gold": A Study on the Pathways for Corporate Transformation Based on the Decision-Making Mechanism of Carbon Trading Pricing—Taking Typical Energy Enterprises along the Yellow River as Examples"), grant number 202410445021. Additionally, this research was also funded by the Undergraduate Research Fund of Shandong Normal University (with the research topic "Research on the Effect of Digital Inclusive Finance on Poverty Reduction and Income Increase in Rural Areas from the Perspective of Common Prosperity"), grant number BKJJ2025012.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are openly available in "China Urban Statistical Yearbook", reference number 9787523001073.

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

Appendix A

When using the entropy method, the determination of weights for each indicator follows these steps:

① Data standardization: To ensure that all indicators have the same units and order of magnitude, data standardization is necessary. The standardization formula is as follows:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{A1}$$

Here, z_{ij} is the standardized data, and x_{ij} is the original data of the j-th indicator for the i-th sample.

② Calculate the proportion of the i-th sample under the j-th indicator: this is the relative share of each sample under each indicator. The formula is as follows:

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} \tag{A2}$$

③ Calculate the entropy value of the *j*-th indicator: The formula is as follows:

$$e_j = -k\sum_{1=1}^{m} p_{ij} \ln p_{ij}, k = \frac{1}{\ln m} \tag{A3}$$

Here, k is a constant, and m is the total number of samples.

④ Calculate the weights of each indicator: the formula is as follows:

$$\omega_j = \frac{1 - e_j}{\sum_{j-1}^{n}(1 - e_j)} \tag{A4}$$

Here, ω_j is the weight of each indicator, and n is the number of indicators.

Appendix B. The Calculation Method of the Variable GTFP

Drawing on the research of Fang et al. [81], this study employs the super-efficiency EBM model, which takes into account undesirable outputs in conjunction with the Global Malmquist–Luenberger (GML) index to measure GTFP. Given that the GML index only reflects the dynamic changes in GTFP for individual time periods, this study follows the approach of Zhang et al. [109] by setting the base period GTFP at 1 and cumulatively multiplying the GML index year by year to obtain the annual GTFP levels for each city within the sample period. The calculation method for the GML index is as follows:

$$\begin{gathered} GML_0{}^{t+1}(x^{t+1},y^{t+1},x^t,y^t) \\ =\{[E_0{}^t(x^{t+1},y^{t+1})E_0{}^t(x,y)]/[E_0{}^{t+1}(x^{t+1},y^{t+1})E_0{}^{t+1}(x,y)]\}^{1/2} \end{gathered} \tag{A5}$$

The GML index can be further decomposed into the product of the technological progress index and the technical efficiency index, with the specific calculation method being

$$\begin{gathered} GML_0{}^{t+1}(x^{t+1},y^{t+1},x^t,y^t) \\ =[E_0{}^t(x^{t+1},y^{t+1})/E_0{}^t(x^t,y^t)] \times \{[E_0{}^t(x^{t+1},y^{t+1})E_0{}^t(x,y)]/[E_0{}^{t+1}(x^{t+1},y^{t+1})E_0{}^{t+1}(x,y)]\}^{1/2} \\ = GTC_0{}^{t+1} \times GEC_0{}^{t+1} \end{gathered} \tag{A6}$$

$$\begin{gathered} GTC_0{}^{t+1} = \{[E_0{}^t(x^{t+1},y^{t+1})E_0{}^t(x,y)]/[E_0{}^{t+1}(x^{t+1},y^{t+1})E_0{}^{t+1}(x,y)]\}^{1/2} \\ GEC_0{}^{t+1} = E_0{}^t(x^{t+1},y^{t+1})/E_0{}^t(x^t,y^t) \end{gathered} \tag{A7}$$

In the formula, F denotes the Directional Distance Function, while x and y represent the input and output vectors, respectively. When calculating GTFP, this study selects labor, energy, and capital as the input factors. The input of labor is proxied by the number of employees at year-end, the input of energy is measured by the total energy consumption, and the input of capital is proxied by the stock of fixed capital. The stock of fixed capital is estimated using the perpetual inventory method, with the specific formula being

$$K_{i,t} = I_{i,t} + (1 - \delta_{i,t})\, K_{i,t-1} \tag{A8}$$

In the formula, i and t denote region and year, respectively; K and I represent the capital stock and total fixed capital formation, with the real value of fixed assets being deflated based on the fixed asset values from 2010 to 2022; and δ indicates the depreciation rate of fixed assets, which is set at 9.6%. This study selects GDP as the desirable output, calculated at constant prices with 2022 as the base year to eliminate the impact of price factors. Undesirable outputs mainly consist of air and water pollution [110]; hence, sulfur dioxide emissions, industrial dust emissions, and chemical oxygen demand are chosen as proxy indicators for undesirable outputs.

Appendix C

The spatial economic–geographic nested matrix, which combines economic differences and geographical distances, can reflect the spatial dependence of economic interactions between regions. This study employs this matrix for spatial econometric analysis, and the construction method is as follows:

$$W_{ij} = f\left(GDP_i, GDP_j, d_{ij}\right) \tag{A9}$$

In the matrix, the element in the i-th row and j-th column represents the interaction intensity between regions i and j. GDP_i and GDP_j denote the economic scales of regions i and j, respectively, while d_{ij} represents the geographical distance between regions i and j. This study uses the centroid distance. Additionally, the diagonal elements of the d_{ij} matrix

are set to zero to reflect zero distance, and an exponential decay transformation is applied to the distance matrix to reflect the distance decay effect.

Next, the economic difference matrix is constructed as follows:

$$E_{ij} = \frac{|GDP_i - GDP_j|}{GDP_i + GDP_j} \tag{A10}$$

$E_{ij} \in [0, 1]$, and a larger value indicates a more significant economic difference.

Then, the nested matrix is constructed as follows:

$$W_{ij} = E_{ij} \times e^{-d_{ij}} \tag{A11}$$

Finally, to ensure that the sum of weights in each row is 1 and to avoid numerical overflow, the nested matrix is standardized as follows:

$$W_{ij}^{*} = \frac{W_{ij}}{\sum_{j=1}^{n} W_{ij}} \tag{A12}$$

After normalization, the diagonal elements are set to $W_{ii}^{*} = 1$, ensuring that the matrix is a diagonal matrix, meaning the weight of a region to itself is 0.

References

1. Acheampong, A.O.; Opoku, E.E.O. Environmental degradation and economic growth: Investigating linkages and potential pathways. *Energy Econ.* **2023**, *123*, 106734. [CrossRef]
2. Xiong, W.; Jiang, M.Z.; Tashkhodjaev, M.; Pashayev, Z. Greening the economic recovery: Natural resource market efficiency as a key driver. *Resour. Policy* **2023**, *86*, 104268. [CrossRef]
3. Ou, Z.X.; Cheng, C.X.; Song, Z.L.; Wu, X.D. Economic resilience of regions within the global supply network in the aftermath of disaster: A case study of Typhoon Mangkhut. *Int. J. Disaster Risk Reduct.* **2025**, *118*, 105275. [CrossRef]
4. Atola, G. Implementing urban resilience in urban planning: A comprehensive framework for urban resilience evaluation. *Sustain. Cities Soc.* **2023**, *98*, 104821. [CrossRef]
5. Andey, B.; Brelsford, C.; Seto, K.C. Rising infrastructure inequalities accompany urbanization and economic development. *Nat. Commun.* **2025**, *16*, 1193. [CrossRef]
6. Gu, X. Strengthening Urban Resilience: Integrating Science, Economy, and Environment for Sustainable Development. *J. Humanit. Arts Soc. Sci.* **2023**, *7*, 2175–2179. [CrossRef]
7. Wu, X.; Yan, Z.; Yang, H.; Wang, S.; Zhang, H.; Shen, Y.; Song, S.; Liu, Y.; Guo, Y.; Yang, D.; et al. Ecological restoration in the Yellow River Basin enhances hydropower potential. *Nat. Commun.* **2025**, *16*, 2566. [CrossRef]
8. Atzkan, O.; Cohen, R.; Yaniv, E.; Rotem-Mindali, O. Urban Energy Transitions: A Systematic Review. *Land* **2025**, *14*, 566. [CrossRef]
9. Zhang, M. Next-Gen TOD: Transforming Transit Oriented Development to Embrace New Challenges and Opportunities. *Urban Rail Transit* **2025**, 1–14. [CrossRef]
10. Fu, F.; Ullah, S. Toward green growth in China: The role of green finance investment, technological capital, and renewable energy consumption. *Environ. Sci. Pollut. Res.* **2023**, *30*, 72664–72674. [CrossRef]
11. Homem de Almeida Rodriguez Correia, G. Increasing transport sustainability through the integration between power grids and electric mobility systems. *npj Sustain. Mobil. Transp.* **2025**, *2*, 17. [CrossRef]
12. Pendam, D.V.; Rofin, T.M. Electric Vehicle and Charging Infrastructure Development: A Comprehensive Review Using Science Mapping and Thematic Analysis. In *Applications of Emerging Technologies and AI/ML Algorithms ICDAPS 2022. Asset Analytics*; Tiwari, M.K., Kumar, M.R., T. M., R., Mitra, R., Eds.; Springer: Singapore, 2023. [CrossRef]
13. Lombardía, A.; Gómez-Villarino, M.T. Green infrastructure in cities for the achievement of the UN Sustainable Development Goals: A systematic review. *Urban Ecosyst.* **2023**, *26*, 1693–1707. [CrossRef]
14. Herath, P.; Bai, X. Benefits and co-benefits of urban green infrastructure for sustainable cities: Six current and emerging themes. *Sustain. Sci.* **2024**, *19*, 1039–1063. [CrossRef]
15. Gong, D.D.; Tian, J.J.; Hu, W.J.; Dong, J.J.; Chen, Y.C.; Ren, R.; Chen, Z.L. Sustainable Design and Operations Management of Metro-Based Underground Logistics Systems: A Thematic Literature Review. *Buildings* **2023**, *13*, 1888. [CrossRef]

16. Moffatt, S. A Guide to Green Infrastructure for Canadian Municipalities. Ottawa: Federation of Canadian Municipalities. 2001. Available online: https://data.fcm.ca/documents/tools/PCP/A_Guide_to_Green_Infrastructure_for_Canadian_Municipalities_EN.pdf (accessed on 13 May 2025).
17. Seidu, S.; Edwards, D.J.; Owusu-Manu, D.; Chan, D.W.M.; Abdulai, S.F.; Buertey, J.I.T. Achieving multifunctionality in green infrastructure projects: A fuzzy evaluation and Gini index of Key drivers in developing countries. *Environ. Dev. Sustain.* **2025**, 1–24. [CrossRef]
18. Hamann, F.; Blecken, G.T.; Ashley, R.M.; Viklander, M. Valuing the Multiple Benefits of Blue-Green Infrastructure for a Swedish Case Study: Contrasting the Economic Assessment Tools B£ST and TEEB. *J. Sustain. Water Built Environ.* **2020**, *6*, 05020003. [CrossRef]
19. Dai, L.; Zhang, R. Environmental Regulation and Green Investment Efficiency: Threshold and Spatial Spillover Analysis for China. *Sustainability* **2025**, *17*, 2934. [CrossRef]
20. Mei, K.L.; Zhang, Z.H. Environmental regulation, green investment and corporate green governance: Evidence from China's New Environmental Protection Law. *Financ. Res. Lett.* **2025**, *76*, 106979. [CrossRef]
21. Cook, L.M.; Good, K.D.; Moretti, M.; Kremer, P.; Wadzuk, B.; Traver, R.; Smith, V. Towards the intentional multifunctionality of urban green infrastructure: A paradox of choice? *npj Urban Sustain.* **2024**, *4*, 12. [CrossRef]
22. Zarei, M.; Shahab, S. Nature-Based Solutions in Urban Green Infrastructure: A Systematic Review of Success Factors and Implementation Challenges. *Land* **2025**, *14*, 818. [CrossRef]
23. Zhao, L.; Zhu, T.; Shi, J.; Kang, X.; Chen, H. Green Investment, Financial Efficiency, and Sustainable Development: Dual Perspectives of Enterprise Cost and Government Guidance. *Appl. Spat. Anal. Policy* **2024**, *17*, 799–821. [CrossRef]
24. Mitra, S.; Madhuvanthi, S.; Sabumon, P. Nature-Based Urban Resilience: Integrating Green Infrastructure. In *Nature-Based Solutions in Achieving Sustainable Development Goals*; Singh, P., Srivastava, P., Sorokin, A., Eds.; Springer: Cham, Switzerland, 2025. [CrossRef]
25. Almulhim, A.I.; Sharifi, A.; Aina, Y.A.; Ahmad, S.; Mora, L.; Filho, W.L.; Abubakar, I.R. Charting sustainable urban development through a systematic review of SDG11 research. *Nat. Cities* **2024**, *1*, 677–685. [CrossRef]
26. Li, C.; Yang, X. The impact of financial agglomeration and the transformation of energy consumption structure on the regional green innovation. *Clean Technol. Environ. Policy* **2025**, 1–15. [CrossRef]
27. Shakya, R.; Ahiablame, L. A Synthesis of Social and Economic Benefits Linked to Green Infrastructure. *Water* **2021**, *13*, 3651. [CrossRef]
28. Simmie, J.; Martin, R. The economic resilience of regions: Towards an evolutionary approach. *Camb. J. Reg. Econ. Soc.* **2010**, *3*, 27–43. [CrossRef]
29. Martin, R. Regional economic resilience, hysteresis and recessionary shocks. *J. Econ. Geogr.* **2012**, *12*, 1–32. [CrossRef]
30. Chao, X.J.; Xue, Z.X. The Impact of New-Type Information Infrastructure on China's Economic Resilience: Evidence from Chinese Cities. *Econ. Res. J.* **2023**, 44–62. Available online: https://kns.cnki.net/kcms2/article/abstract?v=i7m15r_oBqpswhvoejTLPwyqEg5FW9iu5TcvbBU5DnhG9KviWxWNiF35W7zBUewwzws7PKlQWju0iPo5cM4HPZM_WpLgh-uHWwnTxK9-6Afdop-1s8030szpoyX1Zpp7p_e-8lqa8hXBFQq2rA2HnM3-3HboJd7oCCnkAnRlOfdvoDTxFPvGWA==&uniplatform=NZKPT&language=CHS (accessed on 16 June 2025).
31. Wang, J.K.; Fan, Q.X.; Hu, J.Y. Can Regional Integration Enhance Urban Resilience? Based on a Multidimensional View of Urban Resilience. *J. Financ. Econ.* **2024**, *50*, 4–18. [CrossRef]
32. Kou, C.H.; Meng, D.H.; Yang, X.L. Construction and application of economic resilience evaluation model for megacities. *PLoS ONE* **2024**, *19*, e0301840. [CrossRef]
33. Bristow, G.; Healy, A. Innovation and regional economic resilience: An exploratory analysis. *Ann. Reg. Sci.* **2018**, *60*, 265–284. [CrossRef]
34. Wang, H.; Peng, G.; Du, H. Digital economy development boosts urban resilience—Evidence from China. *Sci. Rep.* **2024**, *14*, 2925. [CrossRef]
35. Zeng, L.; Wen, M.; Li, C.; Nie, Y.; Wang, S. Impact of digital greening synergistic transformation on urban economic resilience in China: Evidence from quasi-natural experiments. *Humanit. Soc. Sci. Commun.* **2025**, *12*, 85. [CrossRef]
36. Nie, C.; Zhong, Z.; Feng, Y. Can digital infrastructure induce urban green innovation? New insights from China. *Clean Technol. Env. Policy* **2023**, *25*, 3419–3436. [CrossRef]
37. Liu, M.; Lo, K. Heterogeneous infrastructure and governance of low-carbon transition in Qingdao, China. *Sustain. Sci.* **2025**, 1–18. [CrossRef]
38. Wang, D.; Xu, P.-Y.; An, B.-W.; Guo, Q.-P. Urban green infrastructure: Bridging biodiversity conservation and sustainable urban development through adaptive management approach. *Front. Ecol. Evol.* **2024**, *12*, 1440477. [CrossRef]
39. Lv, J.; Zeng, H.; Liu, Z. The Impact of Green Innovation Capacity on Urban Economic Resilience: Evidence from China's Yangtze River Delta Region. *Sustainability* **2023**, *15*, 15235. [CrossRef]

40. Wang, Z.; Liu, W. A comparative study of urban ecological resilience in the Yangtze River Economic Belt and the Yellow River Basin. *Humanit. Soc. Sci. Commun.* **2024**, *11*, 1471. [CrossRef]
41. Lyu, S.; Huang, Y.N.; Sun, T.S. Urban sprawl, public transportation efficiency and carbon emissions. *J. Clean. Prod.* **2025**, *489*, 144652. [CrossRef]
42. Pan, X.F.; Guo, S.C.; Li, M.N.; Song, J.B. The effect of technology infrastructure investment on technological innovation—A study based on spatial Durbin model. *Technovation* **2021**, *107*, 102315. [CrossRef]
43. Li, C.; Wen, M.; Jiang, S.; Wang, H. Assessing the effect of urban digital infrastructure on green innovation: Mechanism identification and spatial-temporal characteristics. *Humanit. Soc. Sci. Commun.* **2024**, *11*, 320. [CrossRef]
44. Strbac, S.; Kasanin-Grubin, M.; Pezo, L.; Stojic, N.; Loncar, B.; Curcic, L.; Pucarevic, M. Green Infrastructure Designed through Nature-Based Solutions for Sustainable Urban Development. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1102. [CrossRef]
45. Zuniga-Teran, A.A.; Gerlak, A.K.; Mayer, B.; Evans, T.P.; Lansey, K.E. Urban resilience and green infrastructure systems: Towards a multidimensional evaluation. *Curr. Opin. Environ. Sustain.* **2020**, *44*, 42–47. [CrossRef]
46. Nyokum, T.; Tamut, Y. Sustainable Urban Infrastructure Development: Integrating Smart Technologies for Resilient and Green Cities. *SSRG Int. J. Civ. Eng.* **2025**, *12*, 18–36. [CrossRef]
47. Meng, J.Y.; Ye, Z.; Wang, Y. Financing and investing in sustainable infrastructure: A review and research agenda. *Sustain. Futures* **2024**, *8*, 100312. [CrossRef]
48. Shi, Y.; Ge, J. The role of government fiscal and tax incentives in green technology innovation and enterprise development: Implications for human health and hygiene. *Front. Public Health* **2025**, *12*, 1502856. [CrossRef] [PubMed] [PubMed Central]
49. Zhang, L.; Lin, G.; Lyu, X.; Su, W. Suppression or promotion: Research on the impact of industrial structure upgrading on urban economic resilience. *Humanit. Soc. Sci. Commun.* **2024**, *11*, 843. [CrossRef]
50. Li, J.; Fu, G.; Zhao, X. Urban Economic Resilience and Supply Chain Dynamics: Evaluating Monetary Recovery Policies in Global Cities during the Early COVID-19 Pandemic. *Mathematics* **2024**, *12*, 673. [CrossRef]
51. Sato, M.; Kharrazi, A.; Nakayama, H.; Kraines, S.; Yarime, M. Quantifying the supplier-portfolio diversity of embodied energy: Strategic implications for strengthening energy resilience. *Energy Policy* **2017**, *105*, 41–52. [CrossRef]
52. Jonidi Jafari, A.; Charkhloo, E.; Pasalari, H. Urban air pollution control policies and strategies: A systematic review. *J. Environ. Health Sci. Eng.* **2021**, *19*, 1911–1940. [CrossRef]
53. Adebanjo, A.U.; Shafiq, N.; Kumar, V.; Olatoyan, O.J.; Abd Razak, S.N.; Yusof, N.F. Innovative Green Infrastructure Initiatives for Development in the Construction Industry. In *Sustainable Green Infrastructure*; Shaffie, E., Hassan, R., Arshad, A.K., Bhkari, N.M., Sidek, M.N.M., Eds.; Springer: Singapore, 2025. [CrossRef]
54. Golden, H.E.; Lane, C.R.; Adnan, R.; Wu, Q. Improving global flood and drought predictions: Integrating non-floodplain wetlands into watershed hydrologic models. *Environ. Res. Lett.* **2021**, *16*, 091002. [CrossRef]
55. Wang, S.; Song, R.; Xu, Z.; Chen, M.; Di Tanna, G.L.; Downey, L.; Jan, S.; Si, L. The costs, health and economic impact of air pollution control strategies: A systematic review. *Glob. Health Res. Policy* **2024**, *9*, 30. [CrossRef] [PubMed]
56. Wang, X.; Ouyang, L.; Lin, J.; An, P.; Wang, W.; Liu, L.; Wu, L. Spatial Patterns of Urban Green-Blue Spaces and Residents' Well-Being: The Mediating Effect of Neighborhood Social Cohesion. *Land* **2023**, *12*, 1454. [CrossRef]
57. Comunian, R.; England, L.; Faggian, A.; Mellander, C. Positioning Talent: History, Cities and the Growing Importance of Talent. In *The Economics of Talent. SpringerBriefs in Regional Science*; Springer: Cham, Switzerland, 2021. [CrossRef]
58. van Oorschot, J.; Slootweg, M.; Remme, R.P.; Sprecher, B.; van der Voet, E. Optimizing green and gray infrastructure planning for sustainable urban development. *npj Urban Sustain.* **2024**, *4*, 41. [CrossRef]
59. Atanga, R.A.; Wang, Y.; Ayambire, R.A.; Wang, C.; Xu, M.; Li, J. Sister city partnerships and sustainable development in emerging cities: Empirical cases from Ghana and Tanzania. *Habitat Int.* **2024**, *154*, 103208. [CrossRef]
60. Sun, T.; Bian, X.Z.; Liu, J.X.; Wang, R.; Sriboonchitta, S. The economic and social effects of skill mismatch in China: A DSGE model with skill and firm heterogeneity. *Econ. Model.* **2023**, *125*, 106345. [CrossRef]
61. Li, D.; Yao, Q.Y. A pathway towards high-quality development of the manufacturing industry: Does scientific and technological talent matter? *PLoS ONE* **2024**, *19*, e0294873. [CrossRef]
62. Huang, Y.; Gan, J.; Lin, X. City Size, Industrial Agglomeration Pattern Selection, and Urban Economic Efficiency. *Financ. Trade Econ.* **2024**, *43*, 82–95.
63. Du, M.F.; Zhang, Y.J. The impact of producer services agglomeration on green economic development: Evidence from 278 Chinese cities. *Energy Econ.* **2023**, *124*, 106769. [CrossRef]
64. Xu, L.; Luo, Y.; Wu, C.; Umar, M.; Li, H.; Muhammad, S. Environmental regulation and green innovation efficiency: A revisit of the porter hypothesis based on Chinese cities. *Environ. Dev. Sustain.* **2024**, 1–25. [CrossRef]
65. Zhang, L.; Tao, Y.; Nie, C. Does broadband infrastructure boost ffrm productivity? Evidence from a quasi-natural experiment in China. *Financ. Res. Lett.* **2022**, *48*, 102886. [CrossRef]
66. Chen, S.; Wang, D. The Measurement, Decomposition, and Driving Mechanism of Economic Resilience of Chinese Urban Agglomerations. *East China Econ. Manag.* **2022**, *36*, 1–13. [CrossRef]

67. Zhang, L.; Yao, L. The impact of digital technology innovation on urban economic resilience: Evidence from 278 prefecture-level cities and above in China. *J. Manag. Sci.* **2023**, *36*, 38–59. [CrossRef]
68. Ding, J.; Wang, Z.; Liu, Y.; Yu, F. Measurement of economic resilience of contiguous poverty-stricken areas in China and influencing factor analysis. *Prog. Geogr.* **2020**, *39*, 924–937. [CrossRef]
69. Yu, J.; Hu, W.; Deng, T. Towards more resilient economy—Analyzing the impact of new-type urbanization on urban economic resilience: Mechanisms and spatial spillover boundaries. *Econ. Chang. Restruct.* **2024**, *57*, 158. [CrossRef]
70. Zhang, S.L.; Zheng, H.Q.; Zhou, H.Y.; Shao, Q.; Wu, Q. Sustainable land urbanization, urban amenities, and population urbanization: Evidence from city-level data in China. *Soc. Sci. Q.* **2021**, *102*, 1686–1698. [CrossRef]
71. Liu, S.F.; Deng, J. On the model of industrial structure coordination degree and optimization planning of industrial structure in Jiangsu province and China. *J. Grey Syst.* **2021**, *33*, 29–38.
72. Park, J.I. Industrial diversity in building units and factors associated with diversity: A case study of the Seoul Metropolitan Area. *Res. Policy* **2020**, *49*, 103984. [CrossRef]
73. Nie, L.; Wang, Y. Spatial Effects of Service Industry's Heterogeneous Agglomeration on Industrial Structure Optimization: Evidence from China. *Systems* **2024**, *12*, 85. [CrossRef]
74. Rezvani, S.M.; Falcão, M.J.; Komljenovic, D.; de Almeida, N.M. A Systematic Literature Review on Urban Resilience Enabled with Asset and Disaster Risk Management Approaches and GIS-Based Decision Support Tools. *Appl. Sci.* **2023**, *13*, 2223. [CrossRef]
75. Zhao, W.; Toh, M.Y. Impact of Innovative City Pilot Policy on Industrial Structure Upgrading in China. *Sustainability* **2023**, *15*, 7377. [CrossRef]
76. Ma, X.F.; Zhang, R.; Ruan, Y.F. How to Evaluate the Level of Green Development Based on Entropy Weight TOPSIS: Evidence from China. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1707. [CrossRef] [PubMed]
77. Wen, Z.L.; Ye, B.J. Mediation Effect Analysis: Method and Model Development. *Adv. Psychol. Sci.* **2014**, *22*, 731–745. [CrossRef]
78. Chen, X.D.; Liu, Y.; Zhou, K. Research on the Path of Digital Economy to Enhance the Resilience of China's Industrial Chain. *Econ. Syst. Reform* **2022**, *1*, 95–102.
79. Indrianti, N.; Leuveano, R.A.C.; Abdul-Rashid, S.H.; Ridho, M.I. Green Vehicle Routing Problem Optimization for LPG Distribution: Genetic Algorithms for Complex Constraints and Emission Reduction. *Sustainability* **2025**, *17*, 1144. [CrossRef]
80. Khodadad, M.; Aguilar-Barajas, I.; Khan, A.Z. Green Infrastructure for Urban Flood Resilience: A Review of Recent Literature on Bibliometrics, Methodologies, and Typologies. *Water* **2023**, *15*, 523. [CrossRef]
81. Fang, Y.; Liu, Y.L.; Yang, Y.; Lucey, B.; Abedin, M.Z. How do Chinese urban investment bonds affect its economic resilience? Evidence from double machine learning. *Res. Int. Bus. Financ.* **2025**, *74*, 102728. [CrossRef]
82. Sun, X.; Dong, Y.; Shafiq, M.N.; Santos, P.G.-D.; Gillani, S. Economic policy uncertainty and environmental quality: Unveiling the moderating effect of green finance on sustainable environmental outcomes. *Humanit. Soc. Sci. Commun.* **2025**, *12*, 801. [CrossRef]
83. Li, Z.J.; Shi, Y.Y.; Wojewodzki, M.; Wei, Y.G.; Guo, M.Y. The Impact of New-Type Urbanization Policy on Urban Green Total Factor Productivity: New Evidence from China. *Sustainability* **2024**, *16*, 5220. [CrossRef]
84. Gao, B.; Zhang, N.W.; Chen, C.Y. Comprehensive evaluation of urban talent ecological environment and diagnosis of barrier factors: An analysis of 16 cities in Shandong Province. *Expert Syst. Appl.* **2024**, *246*, 123157. [CrossRef]
85. Cao, J.; Law, S.H.; Samad, A.R.B.A.; Mohamad, W.N.B.W.; Wang, J.; Yang, X. Effect of financial development and technological innovation on green growth—Analysis based on spatial Durbin model. *J. Clean. Prod.* **2022**, *365*, 132865. [CrossRef]
86. Du, G.; Li, W. Does innovative city building promote green logistics efficiency? Evidence from a quasi-natural experiment with 285 cities. *Energy Econ.* **2022**, *114*, 106320. [CrossRef]
87. Arogundade, S.; Hassan, A.S. Digital economy and environmental quality of African countries: Evidence from spatial Durbin model. *Environ. Dev. Sustain.* **2025**, 1–18. [CrossRef]
88. Zheng, J.; Guo, Y.X.; Tang, L. Can regional integration cooperation promote industrial structure upgrading?—A quasi-natural experiment based on the Yangtze River Delta Urban Economic Coordination Council. *China Soft Sci.* **2021**, *8*, 1–15. [CrossRef]
89. Feng, R.D.; Wang, K.Y. The direct and lag effects of administrative division adjustment on urban expansion patterns in Chinese mega-urban agglomerations. *Land Use Policy* **2022**, *112*, 105805. [CrossRef]
90. Zhang, H.; Jiang, L.; Zhou, J.; Chu, N.; Li, F. The characteristics and influencing factors of spatial network of city-based innovation correlation in China: From the perspective of high tech zones. *Sci. Rep.* **2023**, *13*, 16289. [CrossRef]
91. Wang, P.; Li, D.H. New energy demonstration cities policy and urban green transformation. *Financ. Res. Lett.* **2025**, *79*, 107261. [CrossRef]
92. Hu, Y.; Connor, D.S.; Stuhlmacher, M.; Peng, J.; Ii, B.L.T. More urbanization, more polarization: Evidence from two decades of urban expansion in China. *npj Urban Sustain.* **2024**, *4*, 33. [CrossRef]
93. Zheng, F.H.; Niu, Y. Environmental Decentralization, Resource Endowment and Urban Industrial Transformation and Upgrading: A Comparison of Resource-Based and Non-Resource-Based Cities in China. *Sustainability* **2023**, *15*, 10475. [CrossRef]
94. Hoffmann, E.M.; Schareika, N.; Dittrich, C.; Schlecht, E.; Sauer, D.; Buerkert, A. Rurbanity: A concept for the interdisciplinary study of rural–urban transformation. *Sustain. Sci.* **2023**, *18*, 1739–1753. [CrossRef]

95. Dmitrović, V.; Ignjatijević, S.; Vapa Tankosić, J.; Prodanović, R.; Lekić, N.; Pavlović, A.; Čavlin, M.; Gardašević, J.; Lekić, J. Sustainability of Urban Green Spaces: A Multidimensional Analysis. *Sustainability* **2025**, *17*, 4026. [CrossRef]
96. Aziz, K.M.A.; Daoud, A.O.; Singh, A.K.; Alhusban, M. Integrating digital mapping technologies in urban development: Advancing sustainable and resilient infrastructure for SDG 9 achievement—A systematic review. *Alex. Eng. J.* **2025**, *116*, 512–524. [CrossRef]
97. Arlati, A.; Nagel, M. Understanding, communicating, and imagining urban biodiversity in German and Italian cities. *npj Clim. Action* **2025**, *4*, 42. [CrossRef]
98. Chen, D.; Hu, W.; Li, Y.; Zhang, C.; Lu, X.; Cheng, H. Exploring the temporal and spatial effects of city size on regional economic integration: Evidence from the Yangtze River Economic Belt in China. *Land Use Policy* **2023**, *132*, 106770. [CrossRef]
99. Li, Y.M.; You, D.D.; Yang, X.; Wang, S.; Ge, R.H. A review of the progress of major infrastructure construction from the perspective of ecological environment based on CiteSpace. *J. Nat. Sci. Harbin Norm. Univ.* **2023**, *39*, 75–80.
100. Semadeni, M.; Withers, M.C.; Certo, S.T. The perils of endogeneity and instrumental variables in strategy research: Understanding through simulations. *Strateg. Manag. J.* **2014**, *35*, 1070–1079. [CrossRef]
101. Pierce, J.R.; Costadone, L.; Mannetti, L.; Morpurgo, J.; Green, C.E.; Halder, M.D.; Guijosa, P.A.L.; Bogan, A.L.; Galt, R.; Hughes, J. Urban Nature Indexes tool offers comprehensive and flexible approach to monitoring urban ecological performance. *npj Urban Sustain.* **2024**, *4*, 22. [CrossRef]
102. Xu, X.J.; Xu, H.; Mei, K.; Tong, L.H.; Liu, Z.J.; Wang, T.T.; Fang, K. Integrating multi-modal data into transformer model for short-term gas consumption forecasting. *Alex. Eng. J.* **2025**, *122*, 655–664. [CrossRef]
103. Gao, Y.L.; Lin, T.T.; Zhang, Y.S.; Luo, S.Z.; Nie, F.P. Robust Principal Component Analysis Based on Discriminant Information. *IEEE Trans. Knowl. Data Eng.* **2023**, *35*, 1991–2003. [CrossRef]
104. Li, X.; Chen, Z.; Chen, Y. The Impact of Digital Talent Inflow on the Co-Agglomeration of the Digital Economy Industry and Manufacturing. *Systems* **2024**, *12*, 317. [CrossRef]
105. Zucaro, A.; Agostinho, F. Urban sustainability: Challenges and opportunities for resilient and resource-efficient cities. *Front. Sustain. Cities* **2025**, *7*, 1556974. [CrossRef]
106. Kolditz, O.; Teti, P.; Dörhöfer, G.; LaMoreaux, J.; Andriani, G.F.; Appleyard, S.; Asch, T.; Buttafuoco, G.; Dietrich, P.; Hursthouse, A.; et al. Environmental Earth Sciences Progress Report 2020 and Outlook 2021. *Environ. Earth Sci.* **2021**, *80*, 314. [CrossRef] [PubMed]
107. Li, Y.; Sun, F.; Li, M.Y. Innovative talent agglomeration, spatial spillover effects and regional innovation performance—Analyzing the threshold effect of government support. *PLoS ONE* **2024**, *19*, e0311672. [CrossRef]
108. Guo, J.; Fu, Y.; Sun, X. Green innovation efficiency and multiple paths of urban sustainable development in China: Multi-configuration analysis based on urban innovation ecosystem. *Sci. Rep.* **2023**, *13*, 12975. [CrossRef] [PubMed]
109. Zhang, M.M.; Wang, K.M. The Impact of Carbon Trading Policy on Green Total Factor Productivity—A Perspective of Technological Progress and Efficiency. *J. China Univ. Pet. Soc. Sci. Ed.* **2024**, *40*, 26–36. [CrossRef]
110. Saxena, V. Water Quality, Air Pollution, and Climate Change: Investigating the Environmental Impacts of Industrialization and Urbanization. *Water Air Soil Pollut.* **2025**, *236*, 73. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.