THE RELATIONSHIP BETWEEN ENVIRONMENTAL REGULATION, COLLABORATIVE INNOVATION AND HIGH-QUALITY ECONOMIC DEVELOPMENT OF CHINA'S FIVE URBAN AGGLOMERATIONS

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ANOVA	Analysis of Variance
ArcGIS	Arc Geographic Information System
BTH	Beijing-Tianjin-Hebei
BTHUA	Beijing-Tianjin-Hebei urban agglomeration
CC	Chengdu-Chongqing
CCUA	Chengdu-Chongqing urban agglomeration
CI	Collaborative innovation
CIE	Collaborative innovation efficiency
CP	Central Plains
CPC	Communist Party of China
CPUA	Central Plains urban agglomeration
DEA	Data Envelopment Analysis
DIW	Discharge of industrial wastewater
DWHTR	Domestic waste harmless treatment ratio
EC	Electricity consumption
EEF	Education expenditure in finance
ER	Environmental regulation
ERE	Environmental regulation efficiency
EST	Employees in scientific research and technical services
FAI	Fixed asset investment
FDI	Foreign direct investment
FE	Financial expenditure
FEM	Fixed effects model
FER	Formal environmental regulation
FTCU	Full-time teachers in colleges and universities
GDP	Gross Domestic Product
GS	Total gas supply
HQED	High-quality economic development
IDE	Industrial sulfur dioxide emissions
IER	Informal environmental regulation
II	Innovation index

IP	The number of invention patents
ISE	Industrial smoke and dust emissions
ISWCUR	Industrial solid waste comprehensive utilisation ratio
IWDRSL	Industrial wastewater discharge reaches standard level
KFE	Knowledge factor efficiency
LB	Loan balance
MEM	Moderating effects model
MFE	Material factor efficiency
NHHC	Number of hospitals and health centres
NMFE	Non-material factor efficiency
OVTS	Output value of tertiary industry/output value of secondary industry
PLC	Public library collections
PRD	Pearl River Delta
PRDUA	Pearl River Delta urban agglomeration
PWEPM	Practitioners in water conservancy, environment and public facility management
R&D	Research and development
S&T	Science and technology
SCU	Students in colleges and universities
SEEF	Science and education expenditure in finance
SEF	Science expenditure in finance
SP	The number of scientific papers
Std. Err.	Standard error
TB	Trade balance
TCG	Total retail sales of consumer goods
TFE	Technology factor stage efficiency
TIET	Total import and export trade
UA	Urban agglomeration
UDSTR	Urban domestic sewage treatment ratio
UR	Urbanisation rate
VISDR	Volume of industrial sulphur dioxide removed
VISR	Volume of industrial soot removed
WS	Total water supply
YRD	Yangtze River Delta
YRDUA	Yangtze River Delta urban agglomeration

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HUBUNGAN ANTARA PERATURAN ALAM SEKITAR, INOVASI KOLABORATIF DAN PEMBANGUNAN EKONOMI BERKUALITI TINGGI LIMA AGGLOMERASI BANDAR CHINA

ABSTRAK

Disebabkan oleh perindustrian dan urbanisasi, kerajaan China semakin menumpukan perhatian kepada pembangunan berkualiti tinggi, berasaskan inovasi, dan mampan. Aglomerasi bandar adalah platform penting untuk tenaga produktif berkualiti baharu dan secara signifikan memupuk persaingan dan kerjasama serantau di China. Berdasarkan data panel dari 95 bandar di China dari tahun 2011 hingga 2021, kajian ini menilai dan membandingkan peraturan alam sekitar, inovasi kolaboratif, dan pembangunan ekonomi berkualiti tinggi bagi lima aglomerasi bandar utama China. Kemudian, ia menganalisis kesan peraturan alam sekitar terhadap inovasi kolaboratif menggunakan model Tobit. Seterusnya, ia menganalisis kesan peraturan alam sekitar dan inovasi kolaboratif terhadap pembangunan ekonomi berkualiti tinggi menggunakan model kesan tetap dan model kesan pemodenan. Keputusan menunjukkan bahawa aglomerasi bandar Beijing-Tianjin-Hebei dan aglomerasi bandar Delta Sungai Mutiara mengatasi aglomerasi bandar Delta Sungai Yangtze, aglomerasi bandar Chengdu-Chongqing dan aglomerasi bandar Dataran Tengah dari segi peraturan alam sekitar, inovasi kolaboratif, dan pembangunan ekonomi berkualiti tinggi. Terdapat trend fluktuasi temporal yang signifikan dan corak pengagihan spatial di antara lima aglomerasi bandar. Dalam aglomerasi bandar Delta Sungai Yangtze dan aglomerasi bandar Dataran Tengah, kesan peraturan alam sekitar terhadap inovasi kolaboratif menunjukkan bentuk U terbalik tidak linear. Dalam aglomerasi bandar Delta Sungai Mutiara dan aglomerasi bandar Chengdu-Chongqing, kesannya

menunjukkan bentuk U bukan linear. Dalam aglomerasi bandar Beijing-Tianjin-Hebei, kesannya menurun secara linear. Dalam aglomerasi bandar Beijing-Tianjin-Hebei dan aglomerasi bandar Dataran Tengah, peraturan alam sekitar tidak mempunyai kesan yang signifikan terhadap pembangunan ekonomi berkualiti tinggi. Dalam aglomerasi bandar Delta Sungai Yangtze, aglomerasi bandar Delta Sungai Pearl dan aglomerasi bandar Chengdu-Chongqing, peraturan alam sekitar memberi kesan positif yang signifikan terhadap pembangunan ekonomi berkualiti tinggi. Dalam aglomerasi bandar Chengdu-Chongqing dan aglomerasi bandar Delta Sungai Yangtze, inovasi kolaboratif menunjukkan kesan pemodenan positif yang signifikan. Namun, tiada kesan pemodenan dalam aglomerasi bandar Delta Sungai Mutiara. Kajian ini memberikan perspektif baru untuk menilai pembangunan dan keseimbangan alam sekitar, inovasi dan ekonomi melalui pengelompokan dan perbandingan aglomerasi bandar.

THE RELATIONSHIP BETWEEN ENVIRONMENTAL REGULATION, COLLABORATIVE INNOVATION AND HIGH-QUALITY ECONOMIC DEVELOPMENT OF CHINA'S FIVE URBAN AGGLOMERATIONS

ABSTRACT

Due to industrialisation and urbanisation, the Chinese government increasingly focuses on high-quality, innovation-driven, and sustainable development. Urban agglomeration is a crucial platform for new quality productive forces and significantly fosters regional rivalry and collaboration in China. Based on the panel data of 95 cities in China from 2011 to 2021, the study assessed and compared the environmental regulation, collaborative innovation, and high-quality economic development of China's five major urban agglomerations. Then, it analysed the impact of environmental regulation on collaborative innovation using the Tobit model. Next, it analysed the impact of environmental regulation and collaborative innovation on high-quality economic development using fixed-effects and moderating effect models. The results show that the Beijing-Tianjin-Hebei urban agglomeration and the Pearl River Delta urban agglomeration outperform the Yangtze River Delta urban agglomeration, the Chengdu-Chongqing urban agglomeration and the Central Plains urban agglomeration in terms of environmental regulation, collaborative innovation, and high-quality economic development. Significant temporal fluctuation trends and spatial distribution patterns exist among the five urban agglomerations. In the Yangtze River Delta urban agglomeration and the Central Plains urban agglomeration, the effect of environmental regulation on collaborative innovation exhibits a non-linear inverted U-shape. In the Pearl River Delta urban agglomeration and the Chengdu-

Chongqing urban agglomeration, the effect exhibits a non-linear U-shape. In the Beijing-Tianjin-Hebei urban agglomeration, the effect is linearly decreasing. In the Beijing-Tianjin-Hebei urban agglomeration and the Central Plains urban agglomeration, environmental regulation had no significant effect on high-quality economic development. In the Yangtze River Delta urban agglomeration, the Pearl River Delta urban agglomeration and the Chengdu-Chongqing urban agglomeration, environmental regulation significantly positively affects high-quality economic development. In the Chengdu-Chongqing urban agglomeration and the Yangtze River Delta urban agglomeration, collaborative innovation showed a significant positive moderating effect. However, there was no moderating effect in the Pearl River Delta urban agglomeration. This study provides a novel perspective to assess the development and balance of environment, innovation and economy through clustering and comparison of urban agglomerations.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In the era of post-industrialisation and digitalisation, the global economy faces structural challenges such as climate change, geopolitical tensions, and the deceleration of globalisation. In response, many countries are shifting from quantity-oriented growth to innovation-led and green development (Auktor et al., 2020). As the world's second-largest economy and top carbon emitter, China is undergoing a profound economic transition, moving toward high-quality, sustainable development. Since the 19th National Congress of the Communist Party of China (2017), the term "high-quality development" has become central to national policy discourse. It requires a shift from extensive, resource-dependent growth toward innovation, environmental sustainability, and coordinated regional development (Xi, 2017). Among the five key principles of this model, innovation, coordination, greenness, openness, and sharing, ecological and innovation-driven development have been especially emphasised (Ren, 2018; Xi, 2017).

Environmental pollution, once seen as an inevitable result of industrialization, is now central to global development agendas (Panel et al., 2011). Guided by the UN's Sustainable Development Goals, countries are promoting green transformation and integrating sustainability into economic planning. China's 14th Five-Year Plan marks a shift toward carbon reduction, pollution control, and qualitative environmental improvements. Environmental pollution presents externalities (Song and Qi, 2022). Given the occurrence of market failure, it is essential to emphasise the government's significant role in environmental regulation. Accordingly, environmental regulation

has become a key policy tool in China's economic governance, especially after the dual-carbon goals were set for 2030 and 2060 (Bai and Rui, 2023).

Meanwhile, innovation has become an essential driving force for global economic growth, social progress and addressing global challenges. Global governments provide substantial backing for science, technology, and innovation through financial support and tax incentives (Michael and Pearce, 2009). Governments in the European Union, the United States, and China have made significant investments in advancing innovative technology research and development and fostering the growth of high-tech industries (Bal and Gill, 2020). The 20th National Congress of the Communist Party of China (CPC) Central Committee pointed out that Innovation is crucial to China's modernisation drive (Xi, 2022b). Collaborative innovation among firms, universities, and governments, has been recognised as key to balancing economic growth with environmental responsibility (Bai and Jiang, 2015; Qing, 2022). It can enhance the allocation of innovation resources across disciplines and borders, serving as a vital method for establishing an innovative nation.

The interplay between environmental regulation and collaborative innovation is theoretically significant and practically urgent. On one hand, based on the Porter Hypothesis, appropriate environmental regulation can stimulate innovation by increasing pressure and providing incentives; on the other hand, excessive or poorly designed regulation may stifle innovation. In the Chinese context, this balance remains a key question, especially within the spatial framework of urban agglomerations, which concentrate both environmental pressure and innovation resources. Therefore, understanding how environmental regulation influences high-quality development through collaborative innovation, and how this varies across different urban agglomerations, is essential for designing effective policy mixes. It not only enriches

the theoretical understanding of sustainable development but also provides practical guidance for differentiated, region-specific policy implementation in China's green transition.

1.1.1 Overview of China's Five Urban Agglomerations

Urban agglomerations have become the fastest-growing spatial units globally, as population and economic activities increasingly concentrate in key regions. Scholars describe this trend as the "victory of cities" (Glaeser, 2011) and the emergence of "planetary cities" (Brenner, 2014). Urban agglomeration development typically progresses through four stages: urbanisation, metropolitan belt, metropolitan circle, and agglomeration. The concept began with the British ecologist Geddes (1915) , who coined "Conurbation" to describe urban clustering driven by improved transport. Over time, cities evolved into interconnected belts (Gottmann, 1957) and circular formations with strong regional influence, such as in the U.S., Japan, and China—where a "metropolitan circle" often aligns with a one-hour commuting radius (Shan and Yang, 2020).

Urban agglomerations are central to China's urbanization and regional development strategy. The 14th Five-Year Plan and Vision 2035 highlight urban agglomerations as key to promoting economic growth and innovation through cooperation. The 2022 "New Urbanisation Plan" further emphasises enhancing their population and economic capacity. As spatial units, the 19 urban agglomerations help address structural challenges in large cities by improving efficiency, quality, and sustainability (China, 2022; Party and Council, 2021). APPENDIX A and APPENDIX B show the geographic location of China's 19 urban agglomerations.

These five urban agglomerations were selected in the study for three reasons, based on their strategic policy roles, spatial representation, and developmental

heterogeneity. Figure 1.1 shows the distribution of China's five major urban agglomerations. The detailed provinces and cities included in the five urban agglomerations can be found in Appendix C.

First, these five urban agglomerations are officially recognised in China's national strategies as core growth poles. The Yangtze River Delta Development Plan (2016), Beijing-Tianjin-Hebei Development Plan (2015), Central Plains Urban Agglomeration Development Plan (2016), and Chengdu-Chongqing Master Plan (2021) have all positioned these urban agglomerations as strategic platforms for high-quality, innovation-driven development.

Second, they are geographically distributed across China's east, south, north, central, and west, ensuring spatial diversity and regional comparability. Their distribution supports an integrated analysis of regional coordination and urbanisation across the country.

Third, the selection reflects the developmental hierarchy in China's urban system. In the "flying geese model" of China's economic development (Zhang et al., 2021), the Pearl River Delta urban agglomeration and the Yangtze River Delta urban agglomeration are leading regions, followed by the Beijing-Tianjin-Hebei urban agglomeration, the Central Plains urban agglomeration and the Chengdu-Chongqing urban agglomeration. This hierarchical structure offers an ideal framework to compare differentiated responses to environmental regulation and innovation policies.

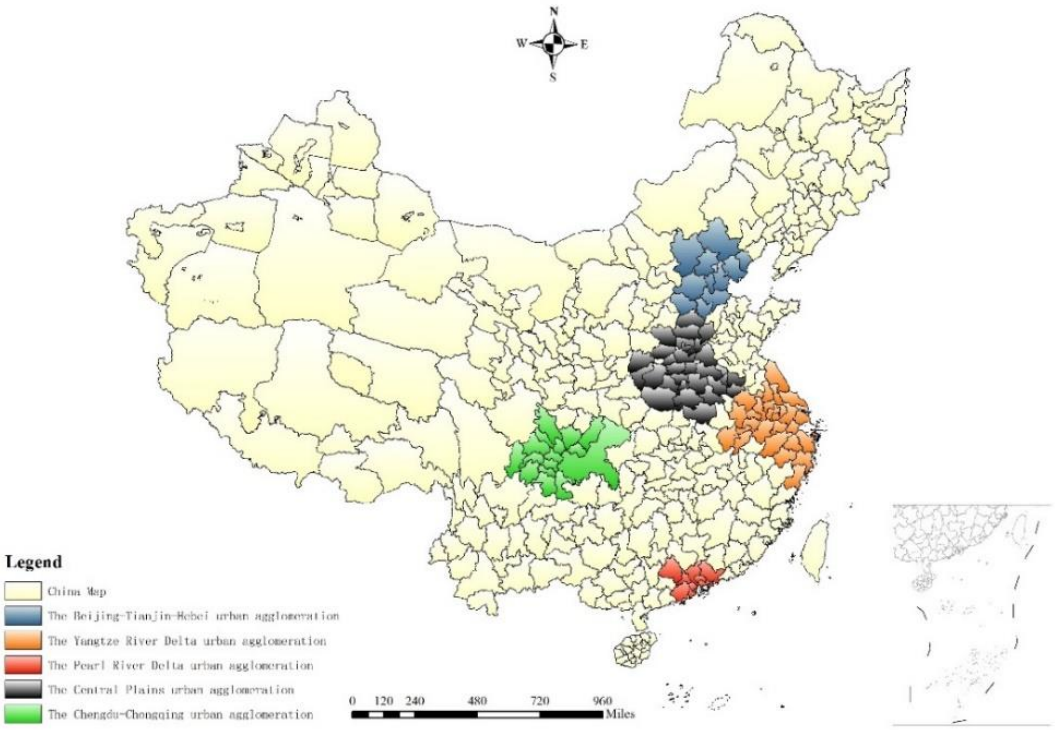

Figure 1.1 The Geographic Location of China's Five Urban Agglomeration

China's five major urban agglomerations differ significantly in historical development, environmental conditions, and economic structures due to distinct regional strategies. These fundamental differences not only shape the unique developmental trajectories of each urban agglomeration but also influence how environmental regulations are implemented, how collaborative innovation evolves, and how high-quality economic development is pursued. Understanding these contextual disparities is essential for analysing the heterogeneous impacts of policy interventions across regions. The comparative summary of the five urban agglomerations can be found in Table 1.1.

In terms of historical development, the Pearl River Delta urban agglomeration was among the earliest beneficiaries of Reform and Opening up, driven by special economic zones (SEZs) and proximity to Hong Kong and Macau (Greater Bay Area (GBA) Initiative). The Yangtze River Delta urban agglomeration grew through financial reform and integration, becoming a key global economic hub. The Beijing-

Tianjin-Hebei urban agglomeration was shaped by the Bohai Rim strategy and recent development of Xiong'an New Area. The Chengdu-Chongqing urban agglomeration gained momentum post-2000 under the Western Development Strategy, while the Central Plains urban agglomeration emerged after 2006 under the Rise of Central China strategy, with Zhengzhou playing a key role.

In terms of environmental conditions, the Beijing-Tianjin-Hebei urban agglomeration has the worst air quality, followed by the Central Plains urban agglomeration and the Chengdu-Chongqing urban agglomeration, due to industrial structure and geography. In contrast, the Pearl River Delta urban agglomeration and the Yangtze River Delta urban agglomeration benefit from cleaner industries and coastal ventilation (China, 2023). Geographically, the Pearl River Delta urban agglomeration, the Yangtze River Delta urban agglomeration, and the Beijing-Tianjin-Hebei urban agglomeration are coastal regions with international trade advantages, while the Chengdu-Chongqing urban agglomeration and the Central Plains urban agglomeration are inland transport hubs linked to the Belt and Road Initiative (Zhang et al., 2021). Innovation and human capital show similar patterns, with the Pearl River Delta urban agglomeration and the Yangtze River Delta urban agglomeration attracting talent, the Beijing-Tianjin-Hebei urban agglomeration struggling with urban saturation, and the Central Plains urban agglomeration facing low labour quality (Zhang et al., 2021).

Economically, according to 2023 China Statistical Yearbook, the Yangtze River Delta urban agglomeration and the Pearl River Delta urban agglomeration lead in total and per capita GDP, followed by the Beijing-Tianjin-Hebei urban agglomeration (Zhang et al., 2021). The Chengdu-Chongqing urban agglomeration and the Central Plains urban agglomeration lag behind, relying more on investment

than consumption or trade. The Pearl River Delta urban agglomeration and the Yangtze River Delta urban agglomeration have more advanced industrial and service sectors, while the Chengdu-Chongqing urban agglomeration and the Central Plains urban agglomeration are catching up.

Table 1.1 Comparative Summary of China's Five Urban Agglomerations

Urban Agglomeration	**Development Path**	**Environmental Condition**	**Industrial and Service Structure**	**Innovation and Human Capital**	**Geographical Position**	**Economic Ranking (GDP)**
The Pearl River Delta urban agglomeration	Early reform; SEZs; GBA Initiative	Good air quality	Advanced; strong services	High innovation; top talent inflow	Coastal; near Hong Kong and Macau	2nd in GDP; 1st in per capita
The Yangtze River Delta urban agglomeration	Financial reforms; global hub	Good air quality	Advanced and diversified	Strong research and development; high living cost	Coastal; global port cluster	1st in GDP
The Beijing-Tianjin-Hebei urban agglomeration	Bohai Rim; Xiong'an Plan	Worst air quality	State-owned dominance; strong services in Beijing	Dense universities; talent pressure	Coastal; internal trade focus	3rd in GDP
The Chengdu-Chongqing urban agglomeration	Western Development Policy	Moderate-poor; basin effect	Industry-heavy, growing services	Educational hub; rising human capital	Inland; Belt and Road Initiative	4th in GDP
The Central Plains urban agglomeration	Rise of Central China (2006+)	Poor air quality	Investment-driven; weak services	Large population; low labor quality	Inland; Eurasian transport hub	5th in GDP

Notes: SEZs means special economic zones; GBA means Greater Bay Area; GDP means Gross Domestic Product

1.1.2 Environmental Regulation of China's Five Urban Agglomerations

Regulation standardizes activities via laws, ensuring market efficiency and addressing failures like pollution (Kahn, 1988). Its theoretical foundation lies in neoclassical economics and sustainable development theory, which address resource scarcity and environmental degradation (Marshall and Guillebaud, 1961; North, 1991). The "Polluter Pays Principle" holds polluters responsible for both prevention and costs (Directorate, 1974), while Coase (1960) emphasized protecting environmental resources as public property to prevent overuse. Environmental regulation is generally defined as the government's efforts to restrict or guide the behaviour of enterprises and individuals through legal, policy and administrative means to reduce negative impacts on the natural environment (Stewart, 1992).

In China, environmental regulation has become central to achieving both ecological protection and high-quality development, reflecting in recent policy and academic discourse (Bai and Rui, 2023; Qian et al., 2023; Shen et al., 2017; Yang and Zhao, 2023).

Across China's five urban agglomerations, environmental regulation has improved, though unevenly. In the Yangtze River Delta urban agglomeration, socio-economic growth in interior cities has surpassed the region's ecological capacity, leading to significant disparities in environmental performance despite progress in core cities like Nanjing (Peng et al., 2020; Ye et al., 2019). This calls for integrated strategies that align environmental governance with sectors such as health, education, and innovation (Deng et al., 2022). The Pearl River Delta urban agglomeration faces worsening ecological pressure due to rapid development. To address this, the government has shifted toward advanced regulatory frameworks promoting low-carbon, low-pollution growth models (Pang et al., 2023; Zhang and Lin, 2022). In the

Beijing-Tianjin-Hebei urban agglomeration, urbanization and ecological protection remain poorly coordinated. Environmental stress continues to rise, highlighting the need for region-specific policies that reflect diverse economic and ecological realities (Han et al., 2021; Wang et al., 2019). The Chengdu-Chongqing urban agglomeration shows regional disparities in ecological governance. Differences between Chongqing and Sichuan in economic strength have led to uneven pollution control investments and regulatory capacity (Shu and Qinghua, 2022). Additionally, strict regulations appear to deter research and development in manufacturing, potentially affecting resource efficiency (Li and Zhou, 2022). In the Central Plains urban agglomeration, a growing decoupling between economic growth and environmental degradation has been observed since 2010, becoming more evident after 2015 (Luo et al., 2021). This indicates effective regulatory efforts to reduce resource intensity, but also highlights the trade-offs in regional economic growth (China, 2010).

1.1.3 Collaborative Innovation of China's Five Urban Agglomerations

Collaborative innovation originates from the synergy theory proposed by Haken (1977), emphasises that interaction and coordination among systems enhance social and economic outcomes. Schumpeter and Backhaus (2003) defined innovation and Abend (1979) expanded it to include management, process, and organisational innovations. Chesbrough (2003) proposed the "open innovation", encouraging enterprises to utilise both internal and external research and development. Building on this, collaborative innovation brings together universities, enterprises, research institutes, and governments to reduce transaction costs and accelerate knowledge transfer (Schartinger et al., 2002; Veugelers, 2012).

In China, collaborative innovation centres on cooperation among industry, academia, and government to improve innovation efficiency and promote economic growth (Wang et al., 2024).

As hubs of innovation resources, urban agglomerations play crucial role in advancing regional integration and high-quality development (Wang and Zhang, 2022). In the Yangtze River Delta urban agglomeration, collaborative innovation has increased significantly, particularly in Shanghai, Southern Jiangsu, and Hangzhou Bay (Wang et al., 2021). However, the region still lacks strong integration among innovation actors (Tao and Zhao, 2022). The Pearl River Delta urban agglomeration shows a rising trend in collaborative innovation, driven by Shenzhen, Guangzhou, and Dongguan. However, disparities in innovation capacity and a core-periphery pattern remain (Zhang and Lin, 2022). The Beijing-Tianjin-Hebei urban agglomeration, China's political centre, has shifted toward industrial and innovation chains. Beijing remains central in the innovation network, but Tianjin and Shijiazhuang are gaining importance. Despite these advances, innovation outcomes still lag behind the Pearl River Delta urban agglomeration and the Yangtze River Delta urban agglomeration (Cui et al., 2024; Deng et al., 2023). The Chengdu-Chongqing urban agglomeration shows promise in innovation-driven growth. However, differences in technological resources among cities hinder overall performance. Government support can mitigate these disparities and enhance cross-city innovation (Sun et al., 2022; Zheng and He, 2022). The Central Plains urban agglomeration has potential due to its central location and open innovation environment. However, it struggles with weak innovation capacity, limited technological output transformation, and insufficient systemic incentives (Chen, 2023; Nadine and Yang, 2023).

1.1.4 High-Quality Economic Development of China's Five Urban Agglomerations

High-quality economic development refers to a shift from traditional, speed-oriented growth to a more sustainable, innovation-driven, inclusive, and efficient model (Kaye Nijaki and Worrel, 2012; Xi, 2022a). It encompasses multiple dimensions including economic efficiency, environmental sustainability, technological innovation, structural optimisation, and regional coordination. Early classical economists like Smith (1937) and neoclassical theorists such as Lucas Jr (1988) and Romer (1986) emphasised capital, labour, and innovation. Institutional economics later highlighted the role of systems and governance (Acemoglu et al., 2005).

In the Chinese policy context, this concept is rooted in the transition advocated by central strategies such as the "New Development Philosophy", the "Innovation-Driven Development Strategy". These initiatives emphasize ecological civilization, coordinated regional development, and innovation as core drivers, aiming to optimize structure, promote ecological protection, and improve public well-being (Wang and Tang, 2022; Xiang et al., 2020).

The economic development level of China's five urban agglomerations has increased, but there are regional differences. The Yangtze River Delta urban agglomeration enjoys rapid growth and high urbanisation but faces regional imbalance. Core cities like Shanghai prosper, while peripheral cities lag behind, limiting integrated development (Jiang et al., 2022; Ye et al., 2019). The Pearl River Delta urban agglomeration has made notable progress since 2015 through innovation and environmental policies. Cities like Shenzhen and Guangzhou lead the shift towards sustainable, innovation-led growth (Zhang and Lin, 2022). The Beijing-Tianjin-Hebei urban agglomeration shows uneven quality. While Beijing and Tianjin are

economically advanced, Hebei trails significantly, with internal fragmentation weakening regional synergies (Deng et al., 2023). The Chengdu-Chongqing urban agglomeration is economically dynamic but still marked by intra-regional disparities. While Chengdu and Chongqing serve as growth poles, peripheral cities struggle with industrial upgrading (Wan et al., 2021; Zheng and He, 2022). The Central Plains urban agglomeration is relatively underdeveloped but has strategic potential. Zhengzhou drives regional growth, yet gaps remain between subregions. Policy support and innovation investment could enhance clustering effects (Peng et al., 2023).

1.2 Problem Statement

China is currently undergoing a critical transition from high-speed growth to high-quality development. While past decades of rapid economic expansion have lifted national income and urbanization levels, they have also revealed deep-seated challenges, including regional economic imbalances, environmental degradation, and uneven factor distribution. Guided by the Five New Development Philosophies, China now seeks to prioritize sustainable, inclusive, and efficient development. In this context, environmental regulation reflects the emphasis on ecological harmony, while collaborative innovation represents openness and shared progress. As key nodes in the national development strategy, urban agglomerations intensify agglomeration effects and boost productivity. The concentration of young populations in core cities has also transformed rural-urban dynamics and urban structures across China. However, these developments have led to a series of unintended consequences, including resource misallocation, surging housing prices, urban ageing, and growing population density in core areas. As a result, many urban agglomerations are increasingly burdened by traffic congestion, environmental pollution, and declining urban liveability.

Three major challenges to economic development have emerged in China's five urban agglomerations (Deng et al., 2021; Ma et al., 2023; Mei and Chen, 2016; Tu et al., 2021; Wei and Li, 2018). First, there is a persistent spatial disparity in development quality, characterised by the pattern "high in the east, flat in the centre, and low in the west". Second, intra-agglomeration inequalities remain evident, with core cities exhibiting stronger innovation capacity and development outcomes, while peripheral cities lag behind. Third, the five urban agglomerations exhibit centre-periphery spatial structures with low spatial correlation, weak interdependence, and insufficient agglomeration effects. These patterns reflect a shift in national priorities, from the pursuit of speed to the pursuit of quality (Chen and Qing, 2022).

Meanwhile, the pressures of urban population concentration, rapid spatial expansion, and accelerated economic activity have heightened issues related to resource scarcity and environmental degradation (Guo and Chen, 2021). Despite institutional reforms intended to promote economic and environmental coordination, policy outcomes have fallen short of expectations (Qiao, 2022). Geographical and industrial heterogeneity contribute to varying environmental conditions across urban agglomerations. Coastal urban agglomerations tend to enjoy better air quality, while inland urban agglomerations suffer from more severe pollution, especially those reliant on heavy industry. As such, the pursuit of a "win-win" outcome between economic growth and environmental sustainability remains a major policy challenge.

Two key problems of environmental regulation have emerged in China's urban agglomerations. First, there is significant regional heterogeneity. For example, while the environmental regulation efficiency of the Beijing-Tianjin-Hebei urban agglomeration has improved, the Yangtze River Delta urban agglomeration has shown a year-by-year decline, and the Pearl River Delta urban agglomeration performs better

than both (Chong et al., 2016). Second, the impact of environmental regulation on economic development varies regionally. In the Beijing-Tianjin-Hebei urban agglomeration, environmental regulation has supported urbanization, though inconsistencies persist between regulatory intensity and urbanization quality (Cui et al., 2018). In contrast, environmental regulation negatively affects economic growth in the Yangtze River Delta urban agglomeration and the Pearl River Delta urban agglomeration (Qin et al., 2021; Tong and Wang, 2018), but has a positive effect in the Chengdu-Chongqing urban agglomeration. Moreover, there is insufficient long-term evidence to confirm the regulatory impact on economic growth across all urban agglomerations (Chong et al., 2016). Given the profound influence of environmental conditions on regional development, environmental governance must become a core pillar of urban agglomeration strategies in China.

Innovation plays a vital role in advancing global sustainability goals (Hamalainen et al., 2018; LupovaHenry and Dotti, 2019). In recent years, although China's innovation capacity has grown significantly, major gaps remain compared to developed countries, especially in core scientific research, high-level education, and basic research and development. Structural weaknesses such as technological bottlenecks and a lack of foundational research capabilities continue to constrain progress.

Among China's five major urban agglomerations, collaborative innovation varies significantly. The Yangtze River Delta urban agglomeration and the Pearl River Delta urban agglomeration have relatively advanced innovation ecosystems (Aijun, 2019), whereas the Beijing-Tianjin-Hebei urban agglomeration, the Chengdu-Chongqing urban agglomeration, and the Central Plains urban agglomeration lag behind. This disparity stems from the lack of functional collaboration mechanisms: the

Central Plains urban agglomeration suffers from weak inter-city division of labour (Zeng, 2008), the Beijing-Tianjin-Hebei urban agglomeration lacks institutional innovation (Mao, 2017), and the Chengdu-Chongqing urban agglomeration faces persistent administrative barriers (Gong et al., 2022). These deficiencies in collaborative innovation contribute to uneven regional development and hinder China's ambition to become a globally competitive innovation-driven economy.

Notably, the isolated examination of environmental regulation and collaborative innovation overlooks their intricate interplay, which is crucial for high-quality development. Theoretically, environmental regulation can act as a catalyst for innovation through the Porter Hypothesis, where stringent regulations incentivize firms to develop cost-saving green technologies, potentially offsetting compliance costs. Conversely, collaborative innovation can enhance the effectiveness of environmental regulation by providing technological solutions for pollution control and resource efficiency. Empirically, however, this interaction remains understudied across China's urban agglomerations. For instance, it remains unclear how different types of environmental regulations (command-and-control, market-based, or voluntary) interact with varying levels of collaborative innovation capacity to influence economic outcomes. Moreover, the spatial heterogeneity in this interaction, shaped by regional economic structures and institutional environments, has not been systematically explored.

In summary, the three major issues facing China's urban agglomerations are rooted in structural, locational, and policy differences in high-quality development, environmental governance, and collaborative innovation. These variations are further compounded by the under-examined interplay between environmental regulation and collaborative innovation, which not only exists across urban agglomerations but also

within them, reflecting deep internal imbalances in resource allocation, innovation capacity, and regulatory implementation.

Although previous studies have explored the relationships among environmental regulation, innovation, and economic development, few have systematically examined how these relationships differ across urban agglomerations. The comparative perspective among urban agglomerations is particularly underexplored. More importantly, there is a lack of integrated research analysing how environmental regulation and collaborative innovation jointly influence high-quality economic development in different regional contexts. This gap limits our understanding of how China can achieve more sustainable and inclusive development through coordinated regional policies, as the synergy or conflict between regulation and innovation may vary significantly depending on local industrial structures, technological capabilities, and policy environments.

China's ongoing transition from high-speed to high-quality growth presents pressing challenges, including regional disparities, environmental degradation, and uneven innovation capacity across its five major urban agglomerations. As national growth poles, these urban agglomerations face distinct developmental constraints, making inappropriate policies ineffective. In response, national strategies such as the Dual-Carbon Targets, the Innovative National Strategy, and the integrated regional development strategy emphasize green transformation, innovation-led growth, and regional coordination. This study provides timely insights into how environmental regulation and collaborative innovation jointly shape high-quality development across urban agglomerations, offering policy-relevant evidence to support more balanced, adaptive, and sustainable regional development.

1.3 Research Questions

This research attempts to determine the relationship between environmental regulation, collaborative innovation and high-quality economic development. This study seeks to investigate the subsequent research questions.

1. How do China's five urban agglomerations differ in terms of environmental regulation, collaborative innovation, and high-quality economic development?

2. What is the relationship between environmental regulation and collaborative innovation of China's five urban agglomerations?

3. How does environmental regulation impact the high-quality economic development of China's five urban agglomerations?

4. Does collaborative innovation moderate the relationship between environmental regulation and high-quality economic development?

1.4 Research Objectives

Based on the research questions above, this study has four research objectives.

1. To compare the differences among China's five urban agglomerations in terms of environmental regulation, collaborative innovation, and high-quality economic development.

2. To examine the relationship between environmental regulation and collaborative innovation in China's five urban agglomerations.

3. To assess the impact of environmental regulation affects high-quality economic development in China's five urban agglomerations.

4. To evaluate the moderating effect of collaborative innovation on the relationship between environmental regulation and high-quality economic development.

1.5 Scope of the Study

The scope of the study covers the essential areas of environment, innovation and economy. Economic development is related to the environment and innovation, but regional heterogeneities exist (Qiao, 2022). The research pays attention to the comparison of environmental regulation, collaborative innovation and high-quality economic development, the relationship between environmental regulation and collaborative innovation, and the relationship between environmental regulation, collaborative innovation and high-quality economic development.

This study focuses on specific geographical locations. China's five urban agglomerations are called "China's five economic growth poles" by the Chinese government, namely the Beijing-Tianjin-Hebei urban agglomeration, the Yangtze River Delta urban agglomeration, the Pearl River Delta urban agglomeration, the Chengdu-Chongqing urban agglomeration and the Central Plains urban agglomeration across China's east, south, north, central, and west. This study includes 95 cities in China's five major urban agglomerations, including 14 cities in the Beijing-Tianjin-Hebei urban agglomeration, 27 cities in the Yangtze River Delta urban agglomeration, 9 cities in the Pearl River Delta urban agglomeration, 29 cities in the Central Plains urban agglomeration and 16 cities in the Chengdu-Chongqing urban agglomeration. Each urban agglomerations have core cities. The core cities of the Beijing-Tianjin-Hebei urban agglomeration are Beijing, Tianjin and Xiong'an new area. The core cities of the Yangtze River Delta urban agglomeration are Shanghai, Hangzhou and Nanjing. The core cities of the Pearl River Delta urban agglomeration are Shenzhen, Guangzhou and Foshan. The core city of the Central Plains urban agglomeration is Zhengzhou. The core cities of the Chengdu-Chongqing urban agglomeration are Chongqing and Chengdu.

1.6 Significance of the Study

The significance of this study is to provide a theoretical and practical discourse on the development of China's urban agglomerations, particularly concerning ecology, innovation and economic development. So far, comparison and correlation analyses of environmental regulation, collaborative innovation and high-quality economic development variables from the perspective of urban agglomeration are relatively rare in previous studies. Based on this, this study contributes to the following content.

1.6.1 Theoretical Significance

This study makes theoretical contributions by empirically applying and contextualizing established theories to China's urban agglomerations, including agglomeration economic theory, the Porter Hypothesis, Schumpeter's innovation theory, and the Environmental Kuznets Curve. While these theories have been widely examined in developed economies, their validity and mechanisms in the context of rapidly industrializing and policy-driven regions like China remain underexplored. By analyzing five major urban agglomerations with distinct regional, economic, and institutional characteristics, this research reveals the heterogeneity of these theoretical relationships in practice.

Specifically, the study investigates whether environmental regulation stimulates innovation as suggested by the Porter Hypothesis, and how this effect varies across developed (The Beijing-Tianjin-Hebei urban agglomeration, the Yangtze River Delta urban agglomeration, and the Pearl River Delta urban agglomeration) and less developed urban agglomerations (The Chengdu-Chongqing urban agglomeration and the Central Plains urban agglomeration). It also explores the joint role of innovation and environmental regulation in shaping high-quality development, contributing to a

better understanding of Schumpeterian innovation processes and the EKC in urbanizing contexts.

Furthermore, the study adopts a factor allocation perspective to guide variable selection, highlighting how infrastructure, fiscal policy, environmental governance, and innovation capacity interact within the agglomeration framework. This cross-disciplinary approach offers a refined empirical lens to examine regional development imbalances and innovation-led growth. Rather than proposing new theories, the study provides important empirical evidence that extends the applicability of established theories to China's unique urban structure, offering insights with both academic and policy relevance.

1.6.2 Practical Significance

This study offers practical implications for enhancing the quality of economic development in China’s urban agglomerations and supporting the implementation of national strategies such as coordinated regional development and green transformation. By comparing the performance of five urban agglomerations in terms of environmental regulation, collaborative innovation, and economic outcomes, the research identifies development patterns, strengths, and bottlenecks specific to each region. These insights help uncover potential innovation hubs and industrial clusters, enabling more efficient resource allocation and strategic planning.

The uneven development across urban agglomerations underscores the need for differentiated policy interventions. Some urban agglomerations have achieved better coordination between environmental governance and economic growth, while others lag in innovation or sustainability. This study provides empirical evidence to support tailored policy recommendations. For instance, strengthening high-tech

innovation in advanced regions and improving infrastructure and public services in less developed urban agglomerations.

Furthermore, understanding whether environmental regulation fosters or hinders innovation and competitiveness allows policymakers to calibrate policy intensity. Proactive yet balanced regulatory approaches can avoid stifling growth while advancing environmental and technological goals. Overall, this study equips governments and planning authorities with data-driven insights to design urban agglomeration-specific strategies that promote synergy among innovation, environmental governance, and economic development, thereby contributing to more balanced and sustainable national growth.

1.7 Organization of Chapters

The following is an overview of the thesis. Chapter 1 analyses the research background, problem statement, research questions, objectives, scope and significance.

Chapter 2 reviews the literature related to the study from four aspects. They are the overview of the theoretical underpinning, the measurement of environmental regulation, collaborative innovation and high-quality economic development, the relationship between environmental regulation and collaborative innovation, and the relationship between environmental regulation, collaborative innovation and high-quality economic development. Then, the gaps in the literature were analysed.

Chapter 3 presents the research design and research methods. This section covers estimation techniques, data collection and variable selection. First, this study evaluates and compares the environmental regulation, collaborative innovation and high-quality economic development of China's five urban agglomerations through DEA, entropy method, and ArcGIS software. Then, the study analyses the relationship

between environmental regulation and collaborative innovation through the Tobit model. Next, the study analyses the relationship between environmental regulation, collaborative innovation and high-quality economic development using the fixed-effects model and moderating effect model.

Chapter 4 evaluates and compares environmental regulation, collaborative innovation and high-quality economic development of China's five urban agglomerations. First, the DEA model measures China's five urban agglomerations' environmental regulation and collaborative innovation. Based on ArcGIS software, this study compares the spatial and temporal differences in collaborative innovation and environmental regulation of China's five urban agglomerations and analyses explicitly the reasons for the differences. Second, high-quality economic development of China's five urban agglomerations is analyzed through the entropy method. Based on ArcGIS software, this study examines the disparities in high-quality economic development among China's five urban agglomerations and thoroughly investigates the underlying reasons for these variances.

Chapter 5 discusses the relationship between environmental regulation, collaborative innovation and high-quality economic development of China's five urban agglomerations. The study employs the Tobit model to examine the effect of environmental regulation on collaborative innovation of China's five urban agglomerations. The fixed-effects model is employed to analyse the influence of environmental regulation on the high-quality economic development. The moderating effect model is employed to analyse the influence of environmental regulation and collaborative innovation on the high-quality economic development. Collaborative innovation serves as a moderating variable.

Chapter 6 summarizes and discusses the research findings and conclusions. This final chapter also presents implications to the literature and theory, limitations of the study and suggestions for future research.