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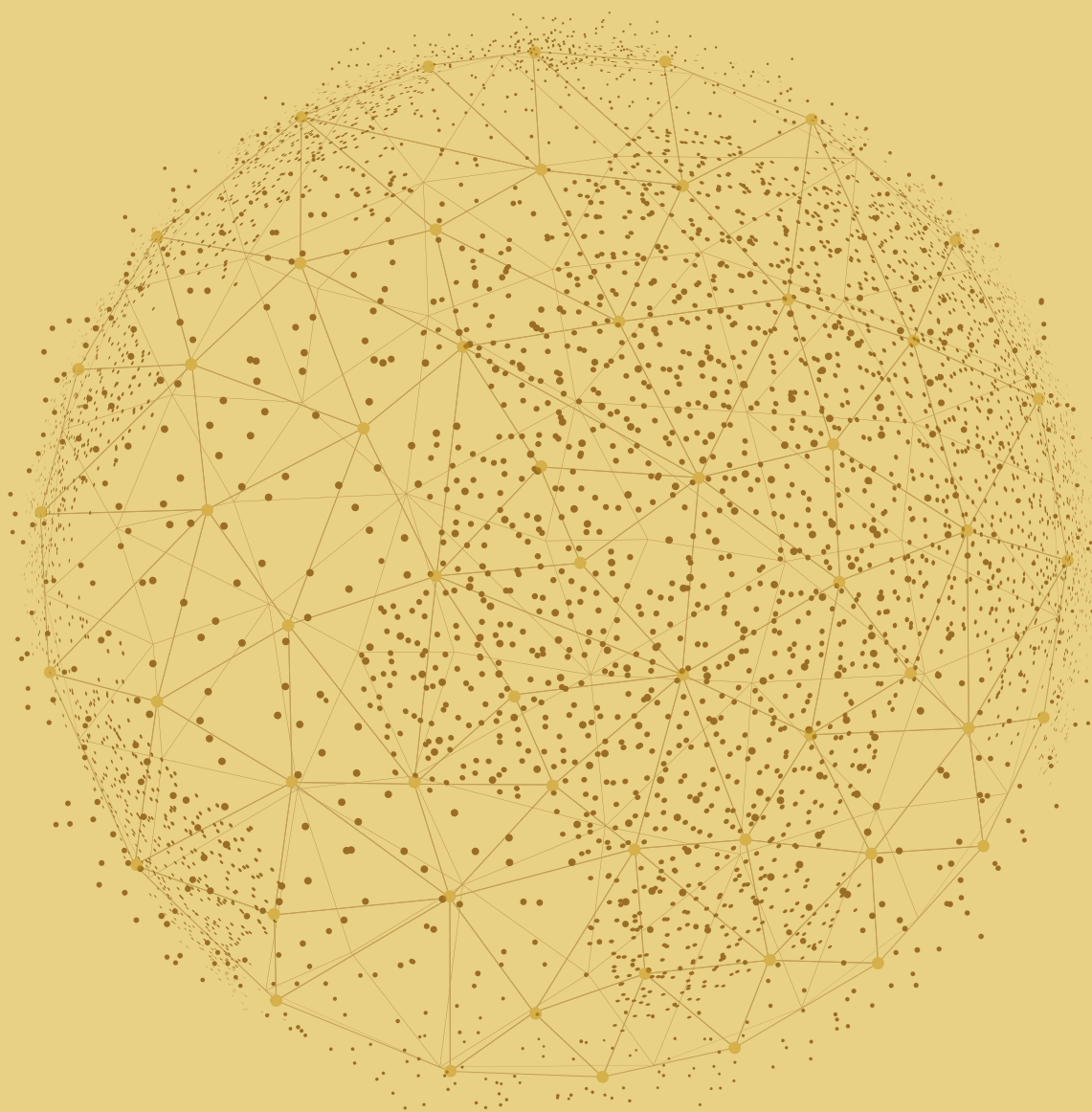


香港青少年文化交流協會
HONG KONG YOUTH CULTURE EXCHANGE ASSOCIATION

Volume 2, Issue 1
March 2026

GLOBAL TRENDS

Youth Perspectives on the Future of Development



Global Trends: Youth Perspectives on the Future of Development

Volume 2, Issue 1 (March 2026)

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Publisher

Publisher: Shanghai-Hong Kong Development Institute, The Chinese University of Hong Kong

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About

Global Trends: Future Researcher Incubation Project

The Project is dedicated to shaping future researchers through interdisciplinary academic learning and practice. Organized by Hong Kong Youth Culture Exchange Association and delivered by Shanghai-Hong Kong Development Institute at the Chinese University of Hong Kong, the Project gathers leading scholars and experts to explore global issues, such as technological advancement, climate change, and economic development. Students benefit from theoretical lectures and practical workshops offered by the University, providing a comprehensive research experience. Our research areas encompass data science, environmental science, social sciences, life sciences, technological innovation, and other interdisciplinary fields. Through personalized programmed design, teamwork, and independent learning focused on real-world challenges, students will gain profound understanding of research methods and academic collaboration. This experience significantly enhances their problem-solving, critical thinking, and innovation skills, laying a strong foundation for future academic and career success.

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Hong Kong Youth Culture Exchange Association is a non-profit organization in Hong Kong that aims to promote cultural exchanges among young people. The organization serves youth aged 3 to 17, with the goal of enhancing communication and integration among young people from Hong Kong, mainland China, and around the world. Through activities such as study tours, competitions, and cultural exchanges, we promote mutual understanding between youth from Hong Kong and mainland China, raise awareness of China's rich cultural heritage, and strengthen their sense of identity with the nation and its diverse ethnic groups.

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Why Do Tea Companies Continue to Promote Paper Straws Despite Their Limited Environmental Friendliness?

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1. Introduction

The global movement against single-use plastics has gained significant momentum in recent years, driven by heightened public awareness of environmental pollution, particularly marine plastic waste. In response, numerous countries and regions have implemented stringent regulations to curb the production and consumption of conventional plastic products. A landmark policy in this regard is China's 2020 plastic ban, which explicitly prohibits the use of non-biodegradable plastic straws in the food service industry, enforcing compliance through substantial penalties such as fines and operational license revocation. This legislative shift has catalyzed a rapid market transformation, creating a vast and urgent demand for alternative products, with paper straws emerging as the predominant substitute.

Few studies have actually explored why companies insist on promoting paper straws. Some people believe that companies do this because they are worried about violating environmental regulations and are afraid of being punished by the government or receiving complaints from consumers. Others think that companies simply want to build an “environmentally friendly” brand image so that they look socially responsible and can attract more customers. Still others point out that many companies have already established long-term relationships with their suppliers, and switching to other types of straws would mean changing the entire supply chain, which is both troublesome and costly. In addition, some argue that companies stick to paper straws because there is still a lack of better alternative materials that are cheap, safe, and environmentally friendly. Due to the lack of systematic research, we still do not know for sure which reason plays the most crucial role.

This study aims to explore the business logic behind companies' strong promotion of paper straws, rather than simply assuming that they are motivated by environmental concerns. It will examine whether firms mainly adopt paper straws because they fear violating regulations, want to build a “green” brand image, find it difficult to change their existing supply chains, or because they genuinely lack better alternative materials. By analyzing the costs, risks, and marketing benefits involved, the research seeks to understand the real economic and strategic reasons driving this choice. The findings may help consumers see through corporate environmental claims and assist policymakers in designing more effective rules that truly encourage sustainable business practices.

Notably, existing research still has many key unanswered questions that hinder a comprehensive understanding of this phenomenon. First, few studies have actually explored why companies insist on promoting paper straws—is it because they fear violating regulations, want to build an eco-friendly brand image, find it hard to change their supply chains, or lack better alternative materials? Second, there is a lack of data on the real environmental impact of paper straws throughout their entire life cycle—from production to disposal—such as how much water and wood are consumed in papermaking, how much energy is used in production and transportation, and whether they can degrade quickly in landfills or marine environments. Third, the health risk assessment of paper straws is also incomplete: while we now know that PFAS are present, there is no long-term research data on the potential effects of prolonged consumption of beverages served with paper straws, or how great these effects might be. Additionally, no comparisons have been made to determine if risks vary across different brands or production processes of paper straws. Fourth, there is little research on how corporate choices, consumer perceptions, and government policies interact with each other—for example, how companies balance regulatory compliance, public image, and consumer satisfaction, and how governments can adjust policies to encourage more truly eco-friendly alternatives. Answering these questions is crucial for understanding corporate environmental practices, the implementation of policies, and the search for reliable eco-friendly solutions.

2. Policies in Mainland China and Hong Kong

Mainland China and Hong Kong have actively promoted the elimination of plastic tableware and the application of paper alternatives for environmental protection. In the mainland, the "plastic restriction order" has set clear timelines: non-degradable plastic tableware was banned in urban catering dine-in services by 2022, and takeout consumption intensity is expected to drop by 30% by 2025 (China.org.cn Finance, 2020). Paper tableware made from straw or wood pulp has been widely adopted in takeout and catering industries.

Hong Kong implemented the first phase of its "plastic reduction order" in April 2024, prohibiting the free supply of 9 types of disposable plastic tableware (People's Daily, 2025). Over 3000 million sets of plastic tableware have been reduced, with 80% of chain restaurant customers refusing takeout plastic utensils (Huanqiu.com, 2024). Paper tableware has become the mainstream alternative, supported by government platforms offering over 2000 eco-friendly options (People's Daily, 2025).

Both regions' efforts show that replacing plastic with paper tableware is practical. Though challenges like paper's heat resistance exist, the policy guidance and public participation are driving a green transformation and contributing to global plastic pollution control (People's Daily, 2020).

3. Relevant Law and Regulation

To address plastic pollution, both mainland China and Hong Kong, China, have rolled out regulations on paper straws, balancing environmental protection with safety compliance.

Mainland China adopts a dual-track approach of plastic restriction and standardization. Nationally, the Guidelines on Further Strengthening Plastic Pollution Control promote paper straws as alternatives to plastic ones, with local supporting rules enforcing the policy in catering businesses. For safety, paper straws must meet mandatory food safety standards like GB 4806.8-2022, controlling heavy metals and microbes. GB/T 44833-2024, effective from May 2025, specifies technical requirements such as raw paper quality and heat resistance. Imported products need customs inspection for compliance.

Hong Kong takes a mandatory ban route via the Amended Product Eco-responsibility Ordinance, enforced since April 2025, which prohibits catering outlets from providing plastic straws, boosting paper straw use. Paper straws here also need to comply with local food safety standards. Though the two regions take different paths, they both set clear compliance boundaries for paper straw production, sales, and use.

4. Triple Synergy of Environmental Protection, Business, and Media Promotion

- i. **Environmental Protection:** Made from renewable materials such as pulp and straw, paper straws can naturally degrade after disposal, reducing microplastic pollution and accumulation caused by plastic straws at the end of their life cycle. This aligns with the current policy direction of limiting and reducing plastic use and meets the social demand for environmental protection.
- ii. **Business:** Paper straws can quickly establish a green and environmentally friendly brand image, precisely attract consumers who care about the environment, and enhance brand recognition. At the same time, they respond to policy requirements, reduce compliance risks, and some enterprises can also receive environmental protection policy support and tax benefits, form a competitive advantage and help increase product premiums and expand the market.
- iii. **Media Promotion:** Environmental protection is a highly publicly concerned topic. Paper straws, as a typical product for plastic reduction, are easily highlighted in media reports, with low dissemination difficulty, wide coverage, and high resonance with the public. Positive media coverage can bring free and extensive exposure to enterprises, meeting the media's traffic needs while helping enterprises promote their brands, achieving a win-win situation.
- iv. **Industrial:** It drives the development of upstream industries such as pulp planting and environmentally friendly paper product processing, as well as downstream industries such as environmentally friendly packaging and waste degradation treatment, promoting the formation of a green industrial chain and balancing economic and social benefits.

5. Core Disadvantages (Triple Conflicts of Environmental Loopholes, Business Risks, and Communication Hazards)

- i. **Environmental Protection:** It is not absolutely environmentally friendly and has obvious environmental costs. First, the production requires a large amount of wood and straw, and excessive extraction will exacerbate vegetation destruction and even encroach on agricultural land, causing resource waste. Second, the papermaking process consumes a large amount of water and requires various chemical reagents. If the sewage treatment does not meet standards, it will cause secondary pollution such as water pollution and soil pollution. Third, some paper straws have coatings to enhance toughness, and the complex coating components will directly affect the degradation effect and create new pollution risks.
- ii. **Business:** First, the production process is complicated, and the raw material, processing, and environmental protection treatment costs are much higher than those of plastic straws, increasing the production costs for enterprises. Moreover, most of the costs are passed on to consumers, reducing the product's cost-effectiveness and affecting market acceptance. Second, the product performance has significant flaws, with poor heat resistance and moisture resistance. They become soft and deformed when exposed to heat and may produce a paper smell, seriously affect the user experience and reduce consumers repurchase intentions, which is not conducive to market promotion. Finally, some enterprises only use paper straws as an environmental marketing gimmick without implementing substantive environmental protection measures, which can easily lead to a trust crisis among consumers, damaging brand reputation and market share.
- iii. **Media Promotion:** First, some media exaggerate the environmental value of paper straws to attract traffic, deliberately avoiding issues such as resource consumption and pollution at the production end, misleading the public's understanding of environmental protection and distorting their judgment of effective environmental protection methods. Second, once the environmental loopholes of paper straws are exposed, the previous excessive promotion will trigger strong public backlash, creating negative public opinion that not only affects the involved enterprises but also makes the public question the entire category of environmental alternatives. Third, media focuses excessively on paper straws as a single product, ignoring that the core of plastic reduction is source reduction and diversified alternatives, narrowing the scope of environmental protection discussions and hindering the overall advancement of environmental protection.

6. Investigation and Statistics

According to a survey, the majority of people are not inclined to use paper straws. Nearly 80 percent of the respondents prefer to use plastic straws. Most people do not tend to use paper straws. Nearly 80% (78.57%) of the respondents prefer plastic straws. In daily consumed beverages, the usage rate of paper straws is also relatively low. Only about 42.86% of people use paper straws for half and plastic straws for the other half. The combined proportion of

respondents who consider paper straws as "a very small part" and "a small part" is approximately 57.14%, indicating that paper straws still account for a minority in daily usage.

The main reason for not using paper straws is their poor durability. As high as 85.71% of the respondents believe that paper straws will become soft and break quickly when soaked in beverages, and they are simply not usable. Only a very small number of people mentioned other reasons such as paper debris falling off or being unaccustomed. Additionally, consumers are generally resistant to the price increase brought by paper straws. More than half (50%) of the respondents clearly stated that they "completely reject" or "do not accept" a slight increase in the price of beverages due to paper straws. Only about 21.43% of people said they could accept it.

7. Conclusion

From the results, it can be seen that the current consumer market has not truly accepted paper straws. Therefore, from a business perspective, maintaining the supply of plastic straws is a reasonable choice that conforms to market logic. However, the harm caused by plastic straws to the environment is already quite obvious. If this contradiction persists for a long time, it will bring continuous pressure to the ecological environment. In the future, if we want to promote the popularization of paper straws, on the one hand, we need to strengthen environmental education for consumers to enhance public awareness of plastic pollution; on the other hand, we must seek breakthroughs in product technology and develop more durable and cost-effective paper straw alternatives to fundamentally balance commercial interests with environmental responsibility.

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How Does the Physical Environment Affect the Physical Health of the Elderly, and How Can This Problem Be Addressed?

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1. Introduction

The concurrent trends of global population aging and rapid urbanization are deeply intertwined. As an increasing majority of the world's population resides in cities, the urban environment becomes the primary setting in which the elderly spend their later years. Consequently, the quality of this environment is fundamentally linked to their health and well-being. While urbanization offers convenience, it also exposes older adults to a complex matrix of physical health risks. Addressing these risks is central to achieving the United Nations Sustainable Development Goals of "good health and well-being (SDG3)" and "sustainable cities and communities (SDG11)," with the creation of "age-friendly cities" as a critical objective.

Within this context, high temperatures, particularly during heatwaves, pose a severe threat to the elderly due to their diminished physiological resilience. Age-related declines in thermoregulatory function, including reduced sweat production and impaired redistribution of blood flow, compromise their ability to dissipate heat. This vulnerability is often exacerbated by a blunted thirst perception, increasing the risk of dehydration. A key research question is: How does prolonged exposure to high ambient temperatures specifically exacerbate cardiovascular and respiratory morbidity and mortality among the elderly? This inquiry is urgent as climate change intensifies the frequency and severity of heatwaves, disproportionately impacting this demographic. A significant research gap exists in translating general knowledge of heat risks into targeted interventions that account for the specific physiological and socio-behavioral profiles of the elderly, such as social isolation and limited access to cooling resources.

Air, an instantaneous necessity for survival, and breathing, a constant activity, make air pollution a ubiquitous and persistent exposure. Therefore, poor air quality is a fundamental determinant of physical health for the elderly. Air pollutants directly damage the respiratory tract and enter the bloodstream via alveolar exchange, triggering systemic oxidative stress and chronic inflammation. This factor acts not only as a primary risk source but also as a potential interactive factor that may amplify the effects of other environmental stressors.

Similarly, noise pollution, an often-invisible environmental stressor, exerts insidious effects on the elderly, who are more vulnerable due to age-related hearing loss, reduced cardiovascular

regulation, and a more fragile nervous system. Chronic exposure to traffic, industrial, and residential noise contributes not only to auditory damage but also to non-auditory issues such as sleep disruption, cognitive decline, and increased cardiovascular disease risk. Current research remains fragmented, often focusing on the general population rather than the elderly's unique circumstances, such as spending more time at home. The cumulative impact of chronic low-level noise on mental health, including anxiety and social withdrawal, is particularly underexplored.

Critically, the community environment serves as the immediate and integrative arena where these factors—heat, pollution, and noise—converge and are experienced daily. The physical and social fabric of a community directly mediates an older adult's exposure and vulnerability. For instance, urban design lacking green space exacerbates the urban heat island effect and limits refuge from pollution and noise, while social cohesion can influence both risk perception and access to support during environmental stressors like heatwaves. Therefore, examining the community context is essential for developing holistic interventions. This study aims to systematically analyze the mechanisms through which high temperatures, air quality, and noise impact the health of the elderly, with particular attention to the mediating role of the community environment. By doing so, it seeks to provide an integrated evidence base for policies that promote age-friendly, sustainable, and healthy urban living.

2. Background

As the global population ages at an accelerating pace, elderly health has emerged as a cornerstone of public health and urban development. Unlike younger demographics, older adults face declining physiological functions and a higher prevalence of chronic diseases, which diminishes their capacity to adapt to environmental stressors. Consequently, they are disproportionately vulnerable to unfavorable physical conditions. Recent research has increasingly underscored the critical role that the living environment plays in maintaining health and preventing disease within this demographic.

Among various physical factors, air quality, extreme heat, environmental noise, and community infrastructure are most closely linked to the physical health and quality of life of the elderly. Air pollution is particularly concerning due to its persistent and unavoidable nature. Long-term exposure is strongly associated with respiratory and cardiovascular issues, as well as an increased risk of premature mortality. Furthermore, poor air quality often compels the elderly to curtail outdoor activities; while this may mitigate immediate exposure, it can lead to long-term declines in physical activity and social engagement.

Beyond air quality, thermal stress and noise pollution pose significant threats. High temperatures can exacerbate pre-existing chronic conditions, while chronic noise disturbance often impairs sleep quality and psychological well-being. At the community level, factors such as lighting, pedestrian safety, and the accessibility of rest facilities shape the daily habits and health behaviors of older residents. However, the relative weight of these environmental factors varies significantly across different community contexts. To better understand these dynamics, further research is needed to integrate objective environmental data with the subjective perceptions of the elderly themselves.

3. Literature Review

The Multifaceted Impacts of the Built Environment on the Health of Older Adults: The built environment, defined by its objective physical characteristics and the subjective perceptions of its residents, is a critical determinant of public health, particularly for the aging population. Older adults exhibit heightened vulnerability to environmental stressors due to age-related physiological decline and social changes. While a well-optimized environment can promote active lifestyles and enhance physical and mental well-being, specific environmental hazards directly threaten health and independence. This review synthesizes evidence on the complex impacts of the built environment, focusing on outdoor structural risks, indoor environmental quality (overheating and air pollution), ambient noise, and the critical mediating role of individual perception.

The Dual Role of the Outdoor Environment: Enabler and Hazard: The community's outdoor environment presents a dual function in healthy aging. Positively, a well-designed environment with accessible amenities, walkable streets, and green spaces encourages physical activity, facilitates social interaction, and improves mental well-being. Empirical studies, such as those in China, correlate a higher density of fitness and entertainment facilities with lower depression rates among the elderly. Conversely, poor environmental conditions—including damaged pavements, absent sidewalks, insufficient lighting, and unsafe public facilities—elevate the risk of falls, a leading cause of injury. Beyond the physical danger, these conditions foster anxiety and fear, which can severely limit mobility and independence, creating a cycle of avoidance and declining health. Research underscores that the health linkages between urban form and well-being are not universally applicable but are profoundly region- and context-specific. Comparative analyses reveal divergent outcomes: Western studies often associate higher urban density with increased active travel, like walking, whereas similar density in some Chinese urban contexts correlates with higher obesity risks. This discrepancy highlights the significant influence of local factors, including lifestyle, dietary patterns, and the specific configuration of urban amenities. This context-dependence necessitates caution in generalizing findings and underscores the importance of localized research and policy-making.

The Mediating Power of Perception: A crucial advancement in this field is the recognition that the relationship between the objective environment and health outcomes is powerfully mediated by individual perception. Objective conditions alone are insufficient predictors of behavior or well-being. Factors such as perceived safety, walkability, accessibility, and overall neighborhood satisfaction often have a more substantial influence on psychological state and activity levels than measurable physical attributes. For instance, a park with smooth paths may remain underutilized if older adults perceive it as unsafe or inaccessible. Therefore, an environment that is objectively walkable may only encourage physical activity if it is also subjectively perceived as secure, pleasant, and welcoming. This underscores the necessity of integrating the lived experiences and subjective evaluations of older residents into urban planning and design processes, moving beyond purely technical or engineering-based approaches.

Indoor Environmental Hazards: Overheating and Air Quality: Given that older adults spend most of their time indoors, the quality of the home environment is paramount. Residential overheating has emerged as a critical threat. Age-related impairments in thermoregulation—such as reduced sweating capacity and diminished cardiovascular reserve—heighten heat intolerance. Consequently, even moderately elevated indoor temperatures can pose severe

health risks during routine daily activities. Exposure to heat is linked to increased morbidity and mortality, with adverse effects often persisting overnight, thereby hindering essential physiological recovery. Vulnerability is socio-economically mediated; studies in low-income communities demonstrate that financial constraints often limit access to cooling resources (e.g., air conditioning), while adaptive behaviors can play a key role in reducing personal exposure. Similarly, indoor and ambient air pollution—notably fine particulate matter (PM_{2.5}) and ozone—constitutes a severe cardiorespiratory threat. Emerging evidence suggests these pollutants can accelerate biological aging through mechanisms like telomere attrition and systemic inflammation, contributing to a broader model of accelerated physiological decline beyond specific diagnosed diseases. This vulnerability is compounded by factors such as residing in older, poorly insulated housing and a greater reliance on walking or public transit, which may increase exposure duration. The intersection of indoor heat and poor air quality presents a particularly complex challenge, especially during heatwaves when the imperative to open windows for ventilation may simultaneously increase the ingress of outdoor pollutants, creating a no-win scenario for residents.

Ambient Environmental Stressors: The Pervasive Impact of Noise: Environmental noise, primarily from road, rail, and air traffic, acts as a chronic and pervasive stressor. Longitudinal studies and meta-analyses robustly link long-term exposure to an elevated risk of age-related cognitive disorders, including dementia and Alzheimer’s disease. Noise also severely disrupts sleep architecture, and older adults are uniquely vulnerable to this disruption due to inherently more fragile sleep patterns. The consequences extend into daytime functioning, contributing to emotional disturbances, increased stress levels, and a measurable decline in overall quality of life and self-rated health. Thus, noise functions not merely as a nuisance but as a significant physiological and psychological stressor that can exacerbate other age-related health declines.

Synthesis and Pathways for Integrated Intervention: Collectively, the evidence confirms that environmental risks to older adults are multidimensional, interconnected, and shaped by a nexus of physiological vulnerability, socio-economic status, and behavioral factors. These risks rarely occur in isolation; a synergistic effect is often observed. For example, a heatwave may coincide with high ambient pollution levels and noise, creating a cumulative stress burden that exceeds the sum of individual effects. This complexity necessitates breaking down traditional silos between public health, urban planning, housing policy, and social services. An effective response requires a hierarchical and integrated intervention framework:

- i. **Primary Prevention (Urban & Building Design):** Prioritize passive, design-based solutions. This includes creating shaded, walkable outdoor spaces with safe, even surfaces; retrofitting housing with improved insulation, reflective materials, and secure night ventilation to combat overheating; implementing noise barriers and traffic-calming measures; and expanding accessible green spaces that serve as multifunctional shelters from heat, noise, and pollution.
- ii. **Secondary Prevention (Targeted Support):** Deploy targeted technological and financial support for the most vulnerable. This involves providing subsidized access to mechanical interventions like air conditioning and air purifiers, backed by energy assistance programs to ensure these solutions are affordable and sustainable for low-income elderly households.

- iii. Tertiary Prevention (Health & Community Systems): Strengthen responsive health and social systems. This includes developing and implementing tailored heat-health action plans and pollution alert systems, coupled with proactive community health outreach. Such programs should focus on monitoring at-risk individuals, managing hydration and medication during extreme events, and providing essential social support, particularly for isolated seniors.

In summary, the built environment profoundly shapes the trajectory of healthy aging through both direct physical pathways and indirect perceptual and behavioral channels. Future research must prioritize understanding the synergistic effects of combined environmental exposures and conduct rigorous evaluations of integrated, cross-sectoral interventions. Ultimately, creating health-promoting environments for aging populations demands proactive, equitable planning that simultaneously addresses tangible hazards and subjective well-being.

4. Methodology

4.1. Study Subjects and Sample Characteristics

This study utilized a structured questionnaire survey, yielding 85 valid responses. The respondent demographic was primarily concentrated within the 50- to 70-year-old age cohort, with a significant majority residing in urban environments. Consequently, the sample serves as a representative baseline for analyzing the living conditions and health perceptions of the urban elderly population.

4.2. Questionnaire Design and Variable Selection

The survey instrument was specifically developed to assess the environment-health nexus among the elderly, with a focus on four primary physical determinants: air quality, thermal stress (high temperatures), acoustic levels (noise), and community infrastructure. Central to this analysis was Question 22, a categorical variable designed to identify the environmental factor subjectively perceived as having the most significant impact on health. This serves as the foundational metric for the study's comparative analysis.

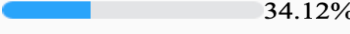
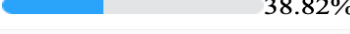
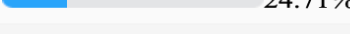
4.3. Data Processing and Analytical Approach

To facilitate a clearer interpretation of trends, certain response categories were merged during the data processing phase. For example, the frequency indicators "frequently" and "occasionally" were synthesized into a binary "impact present" category. This methodological choice was made to prioritize the identification of environmental stressors over the measurement of their specific intensity—a common practice in social science research aimed at revealing macrolevel behavioral and physiological trends.

5. Results Analysis

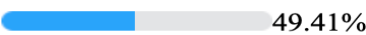
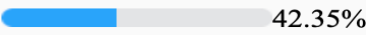
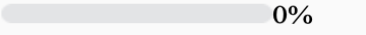
5.1. The Elderly's Awareness of Environmental Health Impacts

第22题 哪一项物理环境因素对您的健康影响最大? [多选题]

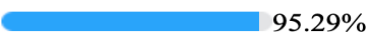
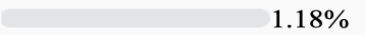
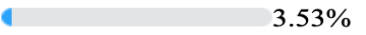
选项	小计	比例
空气质量	63	 74.12%
高温	29	 34.12%
噪音	33	 38.82%
社区环境	21	 24.71%
本题有效填写人次	85	

Regarding Question 22, "Which physical environmental factor has the greatest impact on your health?", air quality emerged as the primary concern with a 74.12% selection rate. This figure significantly outpaces other factors such as noise (38.82%), high temperatures (34.12%), and the community environment (24.71%). These findings suggest that elderly individuals perceive air quality as the most substantial health risk, highlighting that air pollution exerts a more direct and persistent influence on their daily well-being.

第23题 您认为改善物理环境能提高老年人的身体健康吗? [单选题]

选项	小计	比例
非常同意	42	 49.41%
同意	36	 42.35%
一般	7	 8.24%
不同意	0	 0%
本题有效填写人次	85	

第24题 您是否支持政府或社区采取措施改善老年人的居住环境? [单选题]

选项	小计	比例
是	81	 95.29%
否	1	 1.18%
不确定	3	 3.53%
本题有效填写人次	85	

Furthermore, the results from Questions 23 and 24 reveal a profound consensus regarding environmental advocacy: 91.76% of respondents agree or strongly agree that physical environment enhancements directly contribute to improved health outcomes for the elderly. Complementing this, 95.29% expressed support for government- or community-led intervention measures. These figures demonstrate that elderly individuals not only possess a sophisticated understanding of the environment-health nexus but also maintain a highly proactive and supportive stance toward top-down public policy and environmental remediation.

5.2 Supplementary Effects of Heat, Noise, and Neighborhood Conditions

Among specific environmental factors, the impact of air quality on the health of the elderly is particularly pronounced. Survey results show that only 27.06% of respondents rated the air quality in their living environment as "good or very good," with the majority reporting it as "average" or "poor." This reflects the room for improvement in the overall air environment.

When air pollution worsens (e.g., during smog or dust events), 11.76% of the elderly reported experiencing frequent physical discomfort, while 56.47% indicated experiencing occasional discomfort. Overall, a total of 68.23% of respondents reported varying frequencies of physical discomfort under polluted air conditions. Meanwhile, in such situations, only 11.76% of respondents stated that their daily lives were almost unaffected. In contrast, a total of 88.24% of the elderly reported that air pollution affected their daily activities to varying degrees, with over one-third opting to significantly reduce or even avoid going outdoors altogether.

In terms of coping measures, the elderly primarily adopt self-protection methods such as wearing masks (75.29%) and reducing outdoor activities (65.88%). In contrast, the use of active measures to improve indoor environments, such as air purifiers, remains relatively low. This suggests that, when facing air pollution, the elderly tend to rely more on passive adaptation strategies rather than on fundamentally improving their living conditions.

5.3 Supplementary Effects of Heat, Noise, and Neighborhood Conditions

While high temperatures, noise, and community infrastructure yielded lower selection rates in Question 22 compared to air quality, the data confirms that these factors exert a compounded influence on the physiological health and overall quality of life of the elderly.

During periods of thermal stress, nearly half of the respondents reported symptoms such as fatigue, anorexia, or diminished sleep quality. More critically, 45.88% of respondents indicated that high temperatures exacerbate pre-existing chronic conditions. The impact also extends to social dimensions, with over 94% of the elderly stating that extreme heat restricts their outdoor activities and social engagement. This suggests that high temperatures act as a significant barrier to both physical endurance and psychosocial well-being.

Regarding the acoustic environment, over 70% of participants reported that noise pollution disrupts their sleep or restorative rest, while nearly 60% experience psychological distress, including anxiety or irritability. Although noise is seldom identified as the "primary" health determinant, its cumulative effect on mental hygiene and daily comfort is substantial and warrants attention.

Finally, while community factors—such as lighting, road safety, and public amenities—received generally "moderate" assessments, a significant portion of the cohort highlighted

persistent safety concerns and logistical inconveniences. These findings underscore the utilitarian necessity of optimizing the "micro-details" of the built environment to better support the functional independence of the elderly.

6. Discussion

6.1 Comparative Analysis: The Predominance of Air Quality

The findings of this investigation align with established epidemiological literature regarding the vulnerability of the elderly to atmospheric stressors. Previous research consistently indicates that, due to senescent physiological decline, older adults possess a significantly lower threshold for air pollutants compared to younger cohorts, leading to heightened morbidity in the respiratory and cardiovascular systems. The fact that air quality was identified as the paramount health concern in this study validates the heightened risk-awareness among the elderly concerning ambient pollution.

However, where traditional epidemiological studies often focus on clinical outcomes—such as mortality or disease incidence—this research pivots toward subjective perception and behavioral adaptation. By exploring the nexus between environmental exposure and daily conduct, this study highlights that air pollution transcends physical pathology; it acts as a primary catalyst for the contraction of the "life space," forcing a reduction in outdoor mobility and social engagement. This finding provides critical insight into the behavioral consequences of pollution, a dimension frequently marginalized in purely clinical discourse.

6.2 The Synergistic Impact of Thermal, Acoustic, and Built Environments

Existing literature on the health risks of thermal exposure among the elderly suggests that extreme heat acts as a significant physiological catalyst, frequently exacerbating the symptoms of chronic conditions—most notably those involving cardiovascular instability. While the respondents in this study did not categorize high temperatures as their primary health threat, the data reveals a clear correlation between thermal stress and the aggravation of pre-existing ailments, alongside a marked disruption of daily activities. This suggests that the health repercussions of high temperatures manifest not as acute shocks, but as long-term cumulative strain that gradually erodes the physical resilience of the elderly.

Parallel to this, research into the non-auditory effects of environmental noise indicates that its impact on well-being is primarily indirect, mediated through the disruption of restorative sleep and the induction of negative psychological states. The findings of this study corroborate this "invisible" impact, showing that noise pollution consistently interferes with sleep architecture and emotional equilibrium of the elderly. Although its subjective priority is lower relative to air quality, its persistent role in degrading mental hygiene and restorative rest underscores its significance as a critical, yet often underestimated, environmental health determinant.

7. Solutions and Implications

7.1 Prioritizing Air Quality Remediation

Municipal governments and community stakeholders should prioritize air quality interventions in districts with high densities of elderly residents. Strategic measures—including the expansion of urban green space, the optimization of traffic flow, and the mitigation of proximity to localized pollution sources — are essential to reducing long-term respiratory and cardiovascular risks. Furthermore, the promotion of community-led indoor air quality initiatives (such as subsidized filtration systems) can provide a critical buffer for older adults, enabling them to manage health risks more effectively during peak pollution events.

7.2 Integrated Strategies for Thermal and Acoustic Management

To mitigate the impact of high temperatures, the implementation of passive cooling infrastructure—such as increased shading, reflective surfaces, and enhanced natural ventilation—can reduce the physiological strain on the elderly and decrease their reliance on energy-intensive air conditioning. Regarding the acoustic environment, stricter enforcement of zoning regulations and construction hour limitations is necessary. These targeted noise-reduction policies are vital for safeguarding the restorative sleep cycles and psychological well-being of the elderly population.

7.3 Optimizing Age-Friendly Community Infrastructure

At the micro-environmental level, systematic enhancements to pedestrian safety, lighting intensity, and the availability of ergonomically designed public rest facilities are required. By addressing these structural details, communities can minimize the physical risks associated with daily mobility. Such improvements not only foster a sense of safety but also serve as a catalyst for increased outdoor engagement and social participation, ultimately elevating the overall quality of life for the aging demographic.

8. Conclusion

This study utilized a structured survey to examine the nexus between the physical environment and the health perceptions of the urban elderly, specifically evaluating the relative impact of various environmental stressors. The findings establish that air quality is the paramount concern for this demographic, with its perceived significance far outweighing that of thermal stress, acoustic interference, or community infrastructure.

The data reveal that air pollution acts as a dual burden: it serves as a direct trigger for physiological discomfort and a primary catalyst for the contraction of "life space." Because the elderly predominantly employ passive coping mechanisms—such as self-isolation or the cessation of outdoor activities—prolonged exposure to poor air quality may inadvertently lead to a sedentary lifestyle and social withdrawal. These behavioural shifts pose secondary long-term risks to both physical resilience and mental well-being.

Furthermore, while high temperatures and noise pollution are less frequently cited as primary threats, their role as persistent, low-grade stressors cannot be overlooked. Their consistent impact on the exacerbation of chronic conditions, sleep architecture, and emotional equilibrium underscores the necessity of a holistic environmental strategy.

Ultimately, these findings demonstrate that targeted environmental remediation—particularly regarding air quality—is essential for enhancing the quality of life for the aging population. The overwhelming support for public-level interventions documented in this study provides a robust mandate for governments and community leaders to implement age-friendly environmental policies and infrastructure improvements.

9. Limitations

Several limitations of this study should be acknowledged. First, the sample size is relatively modest ($N = 85$) and skewed toward urban residents; the underrepresentation of rural elderly individuals means that the findings may not be fully generalizable across different geographic regions. Second, the reliance on self-reported questionnaires introduces potential subjectivity in respondents' health assessments and environmental perceptions, which may lead to a response bias. Finally, as a cross-sectional study, this research captures a snapshot of perceptions rather than longitudinal trends, meaning it can identify correlations but cannot establish definitive causal relationships.

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The Assault of an Indian Female Doctor: Exploring the Unequal Predicaments Faced by Low-Caste Women in India

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1. Background

This thesis takes the case of a female doctor in India who was assaulted, which caused a social shock, as the entry point to a deeper exploration of the inequality predicament faced by women in Indian society. The research aims to reveal how the caste system systematically oppresses low-caste women, leaving them in an extremely vulnerable position in multiple dimensions such as safety, education, career development, and access to justice. Through case analysis, this paper strives to go beyond the case itself and reveal the deep-seated structural violence and social exclusion mechanisms behind it, and to engage in academic discussions on possible intervention and empowerment paths.

The Indian caste system is mainly divided into four major castes: Brahmins (priests), Kshatriyas (warrior nobles), Vaishyas (commoners), and Shudras (manual laborers), along with the lower-status "untouchables," Dalits. Occupational and social status are inherited by birth, and there is a strict system of endogamy. There is social isolation related to "cleanliness" between different castes. The Indian caste system has long existed in India, with a strict hierarchical social order based on bloodline and religion, and it has a profound impact on various aspects of Indian society, such as politics, economy, and culture. Even though it has been legally abolished, its residual influence has not yet been eliminated, and its impact still persists. The caste-related divisions in rural areas, marriage, politics, and other fields are difficult to erase.

2. Research Question

This study aims to examine the structural inequalities faced by low-caste women in India and to address the following question: How is the caste system sustained within Indian society?

3. Research Objective

Based on the above research questions, this study sets the following specific goals:

i. Mechanism exploration goal

To deconstruct the social and cultural roots and institutional reasons that lead to the plight of low-caste women, with a focus on analyzing the roles of patriarchy, the caste system, economic deprivation, and the state apparatus (especially the judicial and law enforcement systems) in this process.

ii. Policy proposal goal

Based on the analysis, this study proposes targeted and operational countermeasures aimed at protecting the rights of low-caste women and promoting social fairness and justice at multiple levels, such as national policies, legal reforms, social movements, and educational advocacy.

4. Research significance

By further exploring the issue based on existing literature, this study argues that although the caste system in India has been legally abolished, it still exists in various aspects of life. This is because men are the beneficiaries, and they hope to obtain benefits from low-caste women through the caste system. Therefore, they insist on maintaining the exploitation of women through social customs. These benefits refer to economic benefits, patriarchy, and sexual benefits.

5. Relevant Excerpts from the Indian Journal of Language and Linguistics

Between pages 8 and 10, it is illustrated that Dalit women suffer from triple oppression: discrimination due to their status as outcasts or untouchables, gender discrimination under the caste system, and economic hardship caused by wage inequality, low pay, or unpaid labor. (Note: According to the subsequent text, Dalit women also face extreme discrimination in the political sphere.)

At the same time, they are highly vulnerable to gender-discriminatory forms of abuse such as rape, stripping, and nude parades. Relevant real cases can be found on page 8.

The article also highlights a problem: although the Indian Constitution explicitly states: "We, the people of India, solemnly resolve to constitute India into a sovereign socialist secular democratic republic and to secure to all its citizens the following rights: justice—social, economic, and political; liberty of thought, expression, belief, faith, and worship; equality of status and opportunity; and to promote fraternity among all citizens, ensuring individual dignity and national unity," in fact, Indian society and its regulatory institutions have not fully implemented these principles. Cases of persecution across multiple dimensions (gender, caste, economy, politics) against Dalit women are frequent, and they are unable to protect themselves, often suffering from rape, beatings, and sexual harassment.

The fifth and fourth pages from the end of the article focus on the living predicament of Dalit women in India under the oppression of caste, revealing how inequality directly creates and solidifies the wealth gap. Socially, Dalit women account for 16.3% of India's total population, with 18% residing in rural areas. Most of them engage in strenuous domestic work or unpaid agricultural labor. The process of globalization has not improved their situation but has instead exacerbated poverty, forcing some women into the sex trade. Inequality in healthcare is particularly prominent: Dalit women face extremely high maternal and infant mortality rates and lack basic medical security, leaving them with very weak resilience to risk. A single illness can push a family into permanent poverty. The deprivation of educational resources is equally devastating—most Dalit women are illiterate, and the dropout rate among Dalit girls is extremely high. Many are forced to become child laborers, losing the only path to breaking the intergenerational cycle of poverty through the accumulation of human capital via education.

The implicit penetration of the caste system has further worsened their economic situation. The harmful practice of dowry, which was originally not accepted by the Dalit community, has become a new economic burden due to "Sanskritization" (imitating upper-caste customs), aggravating family poverty. In terms of political participation, Dalit women are systematically excluded. Even the few who attempt to run for parliamentary elections face brutal attacks; although some women are appointed to village panchayats (local governing bodies), they cannot challenge the deep-rooted power structure or promote the redistribution of resources toward vulnerable groups.

The article illustrates the connection between this oppression and the wealth gap through several real tragedies: In 2006, Bahnwari Devi, a Dalit social worker in Rajasthan, was gang-raped by five men, including three of her supervisors, for advocating women's health, girls' education, and campaigning against social evils like female foeticide and child marriage. The police initially labeled her "mentally unstable" and delayed arresting the perpetrators for over a year. Her public welfare work was essentially an effort to secure basic conditions for Dalit women to escape poverty. In 2020, a 19-year-old Dalit girl from Hathras village in Uttar Pradesh was brutally attacked and killed by four upper-caste men after refusing their unreasonable demands. The perpetrators threatened to "shoot her brother if she did not submit," exposing the lack of personal safety for Dalit women amid economic vulnerability. Additionally, cases such as three Dalit women in Punjab being tortured by the police in an inhumane manner (including electric shocks to their private parts) and a doctor in Uttarakhand being accused of stealing a Dalit woman's kidney all confirm that Dalit women, due to poverty and low social status, have become the primary targets of violence and exploitation. These violent incidents further restrict their living conditions and opportunities for development, trapping them in a vicious cycle of "poverty → insecurity → deeper poverty." In turn, the wealth gap weakens their ability to resist oppression and seek justice, forming an unbreakable loop.

The first two pages provide an overview of the entire article and identify its key themes, including the class system, the Indian caste system, the Dalit movement and identity, and how these factors collectively contribute to the oppression faced by Dalit women in India. A detailed overview follows below:

The research paper "Classism, Casteism, and Sexism: A Curse in the Life of Dalit Women" explores the complex web of oppression facing Dalit women in India, identifying them as "triple victims" of class, caste, and gender discrimination. While class divisions between the wealthy elite (bourgeoisie) and the working class (proletariat) are universal, the author argues that the

Indian social structure is uniquely stratified by the rigid, religiously sanctioned caste system. This system, rooted in ancient texts like the Laws of Manu and historical events like the Aryan invasion, has systematically excluded "Shudras" or "Dalits" from education, dignified work, and social acceptance for centuries.

Despite modern constitutional guarantees and the work of reformers like Mahatma Gandhi and Dr. B.R. Ambedkar, the paper highlights that these deep-seated prejudices persist, often overriding economic progress. The term "Dalit," meaning "broken men," serves as both a reminder of this historical oppression and a rallying point for political identity and dignity. Through the lens of major literary works, the study aims to bring the "unheard mainstreams" of these marginalized women to light, showing how their lives are dictated not just by poverty but by an inherited status that denies them basic human respect.

Expanding on this, the page three to five delves into Dalit Feminism, distinguishing it as a movement born from the "triple burden" of caste, class, and gender that other feminist movements often overlook. Literary analysis serves as the primary evidence: Mulk Raj Anand's *Untouchable* illustrates this through Sohini, who suffers sexual predation by a priest and domestic abuse, unable to even draw water without depending on high castes. Similarly, Munshi Premchand's *The Shroud* presents a harrowing depiction of dehumanization, where a Dalit woman, Budhia, is neglected to death in childbirth by her husband and father-in-law, who then consume the money meant for her funeral. These narratives, alongside Mahasweta Devi's accounts of tribal injustices, underscore that for Dalit women, the "curse" is not just abstract social stratification but a visceral reality of physical danger, economic servitude, and total moral apathy from both high-caste society and their own kinsmen.

Literature profoundly indicates that Dalit literature is not merely an artistic expression but an extension of its social and political movement. Since the Dalit Panthers movement in the 1970s, modern Dalit literature has emerged in regions like Maharashtra, with its core mission being to expose the plight of the Dalit community, especially Dalit women, to the world and to create awareness (Kharbe, 2021). This literary form encompasses various genres, including poetry, short stories, novels, and autobiographies.

Among these, the autobiography has proven to be the most powerful discursive tool for Dalit women writers. Writers like Urmila Pawar (*The Weave of My Life*) and Baby Kamble (*The Prisons We Broke*) transform personal narratives into political statements. Their writing goes beyond narrating oppression within the household, simultaneously exposing the dual oppression of "home and the world," which stands in sharp contrast to the autobiographies of upper-caste women, that often focus on confinement within the home (Gopal Guru, as cited in Kharbe, 2021). These texts vividly depict structural violence in daily life: from the hardships of long journeys to sell firewood, the absolute lack of medical resources, to the persistent patriarchal violence within families.

The social analysis section of the literature confirms, through a series of horrific real-life cases, that the oppression depicted in literature is not fiction. Examples include the 2006 gang rape of social worker Bhanwari Devi in Rajasthan, where police initially declared her "mentally unstable", and the 2020 Hathras case, where a young girl was sexually assaulted and killed by upper-caste men, with the victim's family pointing to a direct link between the threats and caste dominance (Kharbe, 2021). Furthermore, the literature lists extreme atrocities such as Dalit women being tortured with electric shocks to their private parts by police, having a kidney stolen, or being burned alive for accusing their rapists.

These cases collectively reveal a harsh reality: despite the constitution and laws, Dalit women often face delays, bias, and re-victimization within the justice system when seeking justice. Violence against them is not merely an individual crime but a tool of social terror aimed at maintaining caste and gender hierarchies.

In conclusion, this literature has eloquently demonstrated the oppression suffered by Dalit women from the perspectives of literary criticism and empirical social research. Literature acts as a mirror, reflecting and magnifying social reality, while the atrocities in social reality confirm the depth of the revelations in literature. Through writing and self-organization, Dalit women have transformed from "victims" to "narrators" and "actors", which shows the contribution of Dalit feminist theory to the global theory of social justice.

6. Methodology - Discourse Analysis about Indian Journal of Language and Linguistics

The methodological approach we adopted is text analysis. This research method helps us understand the various viewpoints and attitudes of the academic community regarding the inequality predicament of lower-caste women in India in recent years. It enables us to quickly immerse ourselves in the academic research atmosphere and quickly engage in the academic thinking related to this topic. However, there are drawbacks to using text analysis as the research method. We cannot conduct on-site investigations; we can only glimpse a few aspects of the real situation from existing literature reports. Even the literature reports may misinterpret the truth, and we have no way of knowing.

Nevertheless, after weighing the pros and cons, we ultimately chose text analysis as the research method for this topic. This is due to the following two factors:

- i. From the relevant literature, we have clarified the previous doubts about the historical origin of the "caste system", and clearly understand that the caste system originated in the early Vedic civilization of ancient India, aiming to provide religious legitimacy for social hierarchy. The caste system has also been continuously transformed and strengthened throughout history, eventually permeating all aspects of Indian society and becoming the core force shaping the Indian social structure and culture.
- ii. We cannot truly enter India for on-site investigations, so understanding the relevant information of the topic from existing literature is our best solution.

7. Findings - Case Study

The following three case studies reveal, from different dimensions, the deep-rooted structural inequalities in Indian society. These inequalities interact with widespread poverty to jointly shape the environment in which violence occurs, the capacity of victims to seek justice, and the patterns of societal and institutional response. The analysis will focus on the facts of the cases, data handling, institutional reactions, and the social reality of "inequality and poverty" they reflect, with particular emphasis on dissecting the complexity of the "8.9 Kolkata Intern Doctor Rape-Murder Case."

i. Case 1: The Hathras Gang Rape

Data Analysis and Case Overview:

In 2020, a 19-year-old Dalit girl, Manisha Valmiki, was gang-raped and subjected to fatal violence by four upper-caste men in Hathras, Uttar Pradesh, and died two weeks later. The autopsy report confirmed severe trauma, including a spinal cord injury.

Key data points reveal institutional bias: 1) Initial Police Response: Police refused to file a formal First Information Report (FIR) when the victim's family first approached them, causing a delay of over 10 days. 2) Suspicious Evidence Handling: The victim's body was forcibly and swiftly cremated by police in the early morning hours against the family's vehement objections. This act is widely seen as an attempt to destroy evidence, prevent an independent autopsy, and quell public outrage. 3) Source of Investigative Pressure: Substantive progress in the investigation occurred only after extensive domestic and international media coverage triggered nationwide protests.

Reflected Social Reality (Inequality and Poverty):

This case epitomizes how caste-based inequality directly leads to a lack of judicial protection. The socio-economic status of Dalit families (often linked to poverty) leaves them without the political clout or legal resources to challenge local power structures (often dominated by upper castes).

The logic behind the police actions implies that the life and rights of a lower-caste victim are not deemed worthy of challenging the social status of upper-caste perpetrators or of potential "social disorder." Poverty here refers not only to economic deprivation but also to "resource poverty" in terms of access to rights and justice.

ii. Case 2: 60+ Men Systematically Sexually Assaulted Dalit Girl in Kerala for 5 Years

An 18-year-old Dalit girl was systematically sexually assaulted by 60 or more men over a period of 5 years, including classmates, neighbours, relatives, and even her father's "friends". The perpetrators controlled the victim through filming sexual assault videos and threatening to kill her. The victim's parents, who were working away from home for a long time, were completely unaware of the situation. After the case was exposed, it only received local attention and did not trigger nationwide protests like the cases involving high-caste victims, reflecting the social indifference caused by caste differences.

iii. Case 3: The 8-9 Kolkata Intern Doctor Rape-Murder Case

Case Overview and Forensic Data:

On August 9, 2024, a 31-year-old female intern doctor was raped and murdered inside a seminar room of the RG Kar Medical College and Hospital in Kolkata. The autopsy report provides crucial data: time of death between 3 a.m. and 6 a.m.; injuries included ruptured eyeballs with glass fragments due to violent blows, bleeding in the oral cavity and private parts, and multiple bodily traumas; forensic analysis found approximately 150 ml of semen in the victim's body. CCTV footage showed hospital volunteer Sanjay Roy in the relevant areas around the time of the crime.

Institutional Response and Timeline (Data Analysis):

Kolkata police arrested the main suspect, Sanjay Roy, within a relatively short period (within August) after the crime. This contrasts with the Hathras case. The case directly triggered a massive strike involving over 300,000 doctors across India, leading to the suspension of non-emergency medical services in many regions for several days. Then-Prime Minister Modi publicly addressed the case on August 25, emphasizing women's safety. The suspect was eventually sentenced to life imprisonment on January 20, 2025. However, during the investigation, the Central Bureau of Investigation (CBI) stated on September 17 that there was "no evidence of rape," contradicting the initial autopsy report and causing controversy. Records indicate that the hospital superintendent ordered renovations to the duty room area the day after the crime (August 10). This superintendent was later arrested for "financial irregularities."

Reflected Social Reality (Inequality, Professional Privilege, and Systemic Risk):

The victim, being a doctor, typically implies a higher education and socio-economic status, possibly from a relatively privileged caste background. Yet, she suffered extreme violence in her workplace—a public hospital—which should be safe. This indicates that the risk of gender-based violence is pervasive for women, potentially penetrating the limited protective shield offered by their profession and class. The core issue is the systemic failure in security management within public institutions.

The most striking contrast with the Hathras case lies in the societal response. The medical community is an organized, socially crucial professional class possessing specialized knowledge and social capital. They were able to launch a nationwide strike, instantly creating significant social disruption, thereby compelling a swift and high-level response from the state and judiciary. This powerful collective "bargaining power" is unavailable to impoverished, marginalized Dalit communities. This reveals that inequality exists not only at the moment of victimization but also in the capacity and resources available to seek justice.

The suspect was a "hospital volunteer," a position often distanced from formal, well-paid employment, though his specific socio-economic background is not detailed. The case exposes insufficient investment and managerial gaps in background checks and security measures (especially for female staff on duty) within large public institutions—a form of "poverty" in public resource allocation and governance. Furthermore, the hospital management's haste to renovate the crime scene and the contradictory statements during the CBI investigation suggests a possible institutional tendency to "manage appearances" rather than address root causes.

Comprehensive Analysis Conclusion:

These three cases collectively depict a spectrum of inequality interwoven with caste and class dimensions. Poverty is not merely an economic condition but also a poverty of rights, safety, and access to justice. The Hathras case demonstrates how caste and economic marginalization can lead to complete judicial exclusion; the "honor killing" case shows the violent enforcement of traditional unequal norms in the private sphere; while the Kolkata doctor case indicates that even with a degree of professional status, women remain exposed to risks stemming from systemic safety failures, although privileged groups may possess a stronger capacity to disrupt the system and demand accountability. The social reality in India is that inequality profoundly affects every individual's journey from survival to seeking justice, and the

differential response of state institutions under varying pressures itself becomes a mechanism for reproducing and reinforcing the structures of inequality.

iv. Case 4: The Bhanwari Devi Gang Rape

Data Analysis and Case Overview:

In 1992, Bhanwari Devi, a Dalit social worker in Rajasthan, was gang-raped by five upper-caste men in retaliation for stopping a child marriage while she was working on a government women's rights project.

Key Institutional Biases:

- a) Police Inaction: Refused to register the case and stigmatized the victim, delaying legal proceedings.
- b) Judicial Disparity: Unlike cases with upper-caste victims, this case relied solely on the victim and her supporters for a prolonged legal battle.
- c) Lack of Social Support: Due to her lower-caste status, the case did not spark nationwide protests, showing unequal attention to victims based on caste.

Reflected Social Reality:

This case exposes the dual plight of lower-caste women in India: challenging social norms (opposing child marriage) and their caste identity, which leads to systemic oppression.

The judicial system's passive response reflects the disregard for lower-caste victims' rights, which are seen as less important than the "social order" of upper-caste perpetrators. It also highlights societal indifference to lower-caste women's suffering and their "poverty of resources" in accessing justice and support.

v. Case 5: Systemic Sexual Assault Case of an 18-Year-Old Dalit Girl

Data Analysis and Case Overview:

Within five years since the age of 13, the victim was systematically sexually assaulted by more than 60 men (including classmates, neighbors, relatives, and her father's "good friends"). The perpetrator controlled the victim for a long time by filming sexual assault videos and issuing death threats. The victim's parents did not know about it because they had been working away from home for a long time.

The case has only attracted partial attention, has not prompted a national protest, and media exposure is limited. The victim's family lacks social capital and political resources, making it difficult to ensure an efficient judicial response.

Highlight the Problem:

- a) Structural Indifference: The violence suffered by low-caste victims is often normalized, and it is difficult to break through the caste-class divide to arouse widespread sympathy.
- b) Judicial Marginalization: Law enforcement agencies are slow to respond to low-caste reports, do not actively collect evidence, and receive little institutional attention.

- c) Economic Vulnerability Exacerbates Oppression: The lack of guardianship caused by parents going out to work reflects how economic deprivation exposes low-caste women to danger.

vi. Case 6: Una Case (2022, Gujarat)

Data Analysis and Case Overview:

In 2022, in Una, Gujarat, India, a 19-year-old Dalit girl was abducted by seven high-caste men. The girl was abducted across state lines to a hidden location, illegally detained for a month, and repeatedly raped during this period. The perpetrators repeatedly threatened the victim and her family, forbidding her from reporting the crime to the police, and the victim escaped when the perpetrators were negligent. After escaping, the victim reported to the police, and her family raised their voices through social media and held continuous protests, attracting local attention. Under public opinion pressure, the police arrested all seven involved high-caste men.

Reflected Social Reality:

The remnants of India's caste system are deeply rooted. Dalit women suffer from the dual oppression of caste and gender, with extremely fragile personal safety; society generally ignores cases of low-caste women being victimized, the judicial response is slow, and low-caste groups lack institutional guarantees for safeguarding their rights, echoing the judicial problems highlighted by the 2016 Una Dalit flogging case.

Case Impact:

It did not cause a national sensation, and its influence was limited to the local area and the Dalit community; it further exposed the prevalence of caste violence in Gujarat, prompted reflections on the protection of low-caste women's rights and interests in local areas, and confirmed that the realization of justice for low-caste women relies heavily on the external mobilization of their families rather than institutional support.

Comparison of Similarities and Differences in Cases

Common Ground

- a) Victim status and vulnerability: They are all Dalit women, who are at the bottom of the triple oppression of caste, gender and economy, and their bodies are regarded as inviolable fields for high-caste men.
- b) Identity of the perpetrator: The perpetrators are all high-caste men who use caste privileges to commit violence, reflecting the collusion between patriarchy and caste power.
- c) Failure of the judicial system: Both cases exposed the negligence of law enforcement agencies in reporting cases involving low-caste individuals, and the judicial response was passively dependent on external pressure rather than institutional justice.
- d) The caste logic of social indifference: The case did not trigger a national protest, which proved the "sympathy fault" of society toward the suffering of low castes, and violence was acquiesced to as normal at the bottom.

Difference Points

- a) Form and duration of violence:
 - Case 1 is the systematic exploitation of the long-term "acquaintance society" and penetrates the daily network;
 - Case 2 is a centralized kidnapping and imprisonment, presenting extreme spatial control.
- b) Exposure mechanism:
 - Case 1 relies on sporadic media coverage and lacks continuous public attention;
 - Case 2 is limited to mobilization through social media videos, highlighting the double-edged sword effect of low-caste struggle in the digital age (increased visibility is beneficial but can be easily marginalized by algorithms).
- c) Family role:
 - In Case 1, the family is completely absent from guardianship due to economic migration;
 - In Case 2, the family became the main body of the struggle, but the mobilization ability was limited by caste resources.
- d) Judicial results:
 - The judicial progress of Case 1 is unclear, which may be obscured by local neglect;
 - Although the suspect was arrested in Case 2, the trial process still faced the risk of caste power interference.

The two cases collectively reveal the extreme vulnerability of low-caste women in India under structural violence, while their differences reflect the complex facets of oppressive mechanisms. The first case, involving long-term systemic sexual assault, demonstrates how caste oppression is embedded in the daily networks of an "acquaintance society," achieving sustained exploitation through economic deprivation (migrant parents) and community complicity (perpetrators include neighbors and relatives). This violence is naturalized due to its invisibility, while low-caste families lack the social capital to break the silence, and the judicial system selectively "ignores" it due to caste bias. In contrast, the Una case—featuring kidnapping and cross-state confinement—highlights the absolute spatial control that high-caste men exert over the bodies of low-caste women. However, visual evidence (videos) in the social media era provided a limited lever for family resistance. Yet, such attention remains localized and fragile: the case failed to trigger a nationwide social movement as it would with high-caste victims, confirming how caste hierarchy shapes society's "geography of empathy"—the suffering of low-caste individuals is confined to specific communities and regions, struggling to transform into a universal human-rights issue. In both cases, judicial responses were passively reliant on external pressure rather than on automatic institutional operation, indicating that the legal system itself is permeated by caste logic. Ultimately, these cases jointly point to a harsh reality: the bodies of low-caste women become sites where caste patriarchy exercises power, and whether they obtain justice depends not on the severity of the violence but on whether their families can mobilize limited social attention by overcoming caste-based resource barriers. This "attention injustice" is precisely the core feature of structural violence: it systematically marginalizes the suffering of low-caste women, reproducing their vulnerability.

8. Discussion: The Nested System of Structural Violence and the Dilemma of Resistance

The cases and literature examined in this paper collectively reveal that the plight of low-caste women in India is not a matter of isolated incidents of violence, but rather a system of structural violence nested within the interplay of the caste system, patriarchy, class exploitation, and state failure. This system exhibits the following core characteristics:

The cases and literature discussed in this article jointly reveal that the predicaments faced by low-caste women in India have the following core characteristics:

i. The normalization and spatialization of violence

Violence is not only manifested in extreme cases such as rape and murder, but also permeates daily life from being denied access to water and medical care to sexual harassment in the workplace and neglect at home. Both public spaces (fields, water sources) and private spaces (families) pose threats to Dalit women, demonstrating the spatial ubiquity of violence. The five-year-long community sexual assault in Case One is an extreme manifestation of this normalized and familiar violence.

ii. The complicit failure of the judiciary and the state

The state is supposed to be the guarantor of rights, but its law enforcement and judicial systems often become part of structural violence.

iii. Caste-based stratification of social attention

The differences in public response to the case of the female doctor, the Una case, and the case of the 18-year-old girl clearly reveal the caste boundaries of social empathy and mobilization. The suffering of high-caste or professional elite women can more easily evoke a national "us" response, while the hardships of Dalit women are confined to the "other" category, making it difficult to break through regional and community barriers and gain universal human rights attention. This "empathy gap" is a key social-psychological foundation for maintaining structural violence.

iv. The narrowness and paradox of resistance paths

Dalit literature and social media have become important tools for resistance, transforming private pain into public political statements. However, this resistance also faces paradoxes: on the one hand, digital mobilization may bring attention (such as in the Una case), but it may also invite more brutal retaliation; on the other hand, limited judicial victories (such as the arrest of suspects) often fail to shake the deep power structure and may instead create the illusion that "the problem has been solved."

9. Recommendations: Toward an Integrative Path of Decasteification and Gender Justice

Addressing the plight of low-caste women requires moving beyond piecemeal legal amendments or symbolic policies to adopt systemic reforms that are integrative, decasteifying, and centered on community empowerment.

9.1 National Policy and Legal Reform Level

9.1.1 *Establish Specialized Judicial and Law Enforcement Bodies*

Create fast-track special courts and dedicated police units for Caste- and Gender-Based Violence (CGBV) at central and state levels, staffed with judges and officers trained in anti-caste discrimination, enforcing strict timelines for filing cases and investigations.

9.1.2 *Economic Empowerment and Resource Guarantees*

Strictly enforce land reform policies to ensure Dalit women's rights to own and control land. In public employment schemes (e.g., MNREGA), guarantee equal participation and equal wages for low-caste women, coupled with childcare facilities.

9.1.3 *Health and Education Affirmative Action*

Implement stringent monitoring and accountability mechanisms against caste discrimination in Primary Health Centers and schools. Scale up educational incentive programs for low-caste girls (e.g., scholarships, transport stipends) and develop decasteified curricula.

9.2 Judicial and Law Enforcement System Transformation Level

9.2.1 *Adopt "Structural Litigation" Strategies*

Encourage human rights organizations to file public interest litigations on behalf of entire victim classes in cases of recurrent pattern-based violence (e.g., mass sexual assaults in villages), forcing systemic change.

9.2.2 *Evidence Rules and Victim Protection Reform*

Abolish discriminatory evidentiary requirements in practice (e.g., demanding proof of extreme resistance). Establish comprehensive victim and witness protection programs to prevent retaliation.

9.2.3 *Severely Punish Law Enforcement Complicity*

Implement a "zero-tolerance" policy against police and officials who shield perpetrators, destroy evidence, or abuse victims, holding them criminally accountable.

9.3 Social Movements and Civil Society Level

9.3.1 *Build Cross-Caste-Gender Solidarity Alliances*

Foster strategic alliances between Dalit women-led organizations and mainstream women's movements, labor movements, and student movements, placing the anti-caste agenda at the core of gender justice and socio-economic rights struggles.

9.3.2 *Innovate Public Advocacy Methods*

Utilize documentaries, social media narratives, Dalit literature, and theatre to continuously tell the life stories of low-caste women, challenging the emotional detachment of upper-caste society and fostering a new ethics of empathy.

9.3.3 Strengthen Grassroots Community Watch Networks

Fund and train community health workers and legal facilitators within low-caste communities to establish early warning and support systems, combating the normalization of everyday violence.

9.4 Culture and Education Advocacy Level

9.4.1 Deconstruct "Honor" and "Purity" Narratives

Systematically critique, through mass media and schooling, the patriarchal-caste ideology that binds women's bodies to caste "honor," promoting gender notions based on autonomy and dignity.

9.4.2 Promote Critical Caste Education

Introduce mandatory curricula at all educational levels on the history, functioning, and intersection with gender exploitation of the caste system, fostering critical consciousness among younger generations.

10. Conclusion

The path to liberation for low-caste women in India is, in essence, the path toward the democratization and de-feudalization of Indian society itself. It demands a profound revolution that simultaneously challenges vertical caste stratification and horizontal gender oppression. Only when laws move from "paper" to "practice," social empathy bridges the caste divide, and low-caste women themselves become the agents and leaders of change, can the nested system of structural violence be truly dismantled, allowing dignity and justice to reach all citizens.

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The Challenges of AI Development Speed and Data-Privacy Protection

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Abstract

This study examines how the U.S. risk-based regulatory system achieves a balance between AI advancement and data privacy protection in a context of global data resource constraints. The research question is: “To what extent does the U.S. risk-based AI regulatory framework effectively balance AI development acceleration with data privacy protection amid global resource constraints?”

In this research, we have analysed the promotion of AI investment, the effectiveness of personal data protection, and the balance between these two factors, focusing on U.S. risk-based AI regulation and comparing it with regulatory models in the EU and China. This research uses qualitative methods to analyse those differences, using authoritative reports and data.

As a result of this research, it is found that the U.S. risk-based approach is effective in the promotion of innovation; however, there is an imbalance in the aspect of privacy. Therefore, there is a need to strengthen federal-level privacy standards and data transparency.

1. Introduction

What happens when the very resource that powers artificial intelligence begins to run out, while the methods used to collect it significantly violate individuals’ privacy? AI has delivered substantial societal benefits, yet these advances are constrained by emerging technical limits and ethical challenges.

Over the past two decades, artificial intelligence has developed rapidly and revolutionized the information era. Data and knowledge have become more accessible to people, especially low-income citizens. This has brought us closer to equity in information access. However, these benefits are increasingly constrained by technical limitations in data availability and ethical concerns over privacy.

Projected exhaustion of high-quality training data by the late 2020s–early 2030s may incentivize intensified web scraping, exacerbate privacy violations and heighten the need for effective regulation. Epoch AI estimates that the effective storage of human-generated and

publicly available text is approximately 300 trillion tokens (Villalobos et al., 2024) after quality and repetition adjustments. If this trend continues, we expect language models to fully utilize this storage by 2032 (Villalobos et al., 2024). This indicates that high-quality human-generated text data could be exhausted between 2026 and 2032 if current training trends continue. Additionally, they have mentioned that the rapid scaling seen since 2020 will likely decelerate (Edelman & Ho, 2025) as larger-scale compute investments require longer lead times. These kinds of physical and data limitations threaten to slow the growth of AI progress over the past decade.

Moreover, at the same time, the data privacy problem has become more severe as AI companies engage in large scale data collection. Training data is often gathered from the internet without users' permission. This has raised significant legal and ethical concerns. The IAPP notes that AI developers training models on personally identifiable data obtained through web scraping have faced a wave of lawsuits (IAPP, 2023), citing *PM v. OpenAI LP* as an example (IAPP, 2023) alleging the use of personal information without any consent. The Italian Data Protection Authority fined Clearview AI €20 million (IAPP, 2023) for scraping biometric data from the web, highlighting growing regulatory scrutiny of AI data collection practices worldwide.

To solve these problems, we need strong regulation on AI. The United States, as a global leader in AI development with \$109.1 billion in private AI investment in 2024 (Stanford HAI, 2025), has adopted various regulations that attempt to balance innovation with protection. However, there is no comprehensive federal AI law in the US yet. Not only does this piecemeal approach fail to ensure compliance, but it is also insufficient to achieve the goal of privacy.

This study examines the effectiveness of U.S. AI regulation in balancing innovation speed with data privacy protection, focusing on how risk-based regulatory frameworks can optimize both AI development and user privacy protection under global resource constraints.

Our research question is “To what extent does the U.S. risk-based AI regulatory framework effectively balance AI development acceleration with data privacy protection amid global resource constraints?”

This study evaluates the effectiveness of the U.S. risk-based AI regulatory framework in balancing AI development acceleration with data privacy protection amid global resource constraints. Through comparative analysis with EU and Chinese regulatory approaches, we identify both strengths and limitations of the current U.S. framework and propose areas for improvement.

2. Literature review

2.1 Theme 1: AI investment & development

- i. Source 1: Stanford HAI AI Index Report 2025 (Stanford Institute for Human-Centered Artificial Intelligence, 2025)

Noteworthy examples of data regarding AI development, investment, and regulation can also be found in the Stanford HAI AI Index Report 2025. For instance, as supported by the report,

in 2024, private AI investment in the United States reached \$109.1 billion (remove “dollars” for correctness). This maintained America’s position as the global investment leader in artificial intelligence. Furthermore, we can also obtain data regarding AI incidents. According to the report, there has been a 56.4 percent increase in incidents in 2024 regarding data breaches or issues of algorithmic bias. Concerning regulation, we notice a high increase in the development of state-specific AI regulation; in fact, there are now 131 state-specific regulations in 2024, as opposed to 49 in 2023.

The report claims that currently, the USA is leading in AI investment because of its flexible decentralized system of regulation. However, there is a drawback to this system. A decentralized system means that there is no set system of federal regulation, and each of the states is free to make its own set of rules. This is good for innovation, but the fact that there is no single policy on privacy might have contributed to these AI-related incidents.

Stanford HAI is an influential and prominent research and study hub that focuses on AI governance as its domain expertise. This report provides empirical data, which is fact-based and available to us as of 2025, including investment amounts, incident rates, and legislation figures, which are all reported and stated as facts in various studies and academic literature as well. However, it fails to analyze how certain state-specific regulations on risk-based regulation influence investment or privacy. Furthermore, there is no element of classification of incidents of AI based on risk levels. It also lacks an analysis of actions by federal agencies to support state-specific regulations.

This source is an essential component of the factual data needed to support our hypothesis. The \$109.1 billion figure for investments substantiates the idea that the risk-based system safeguards innovation within the U.S. At the same time, the increase itself – totaling 56.4% – confirms the presence of a protection gap regarding privacy. Through this, we can directly examine the question of whether the framework in the U.S. achieves a balance between the acceleration of AI development and privacy protection.

ii. Source 2: AI watch: Global regulatory tracker - United States (White & Case LLP, 2025)

This is a legal tracker that focuses on providing detailed insights into AI legal developments in the U.S. jurisdiction. This tracker shows that there is no federal AI legislation, and that federal policies must rely on state laws. This means that the Colorado AI Act is a landmark law that is effective from 2026 and is based on a classification approach to AI. This is further categorized into low, moderate, and high AI classification with corresponding regulatory requirements. High AI classification requires conducting privacy audits for healthcare and finance. California has introduced bills that require people to opt out of automatic decisions that have serious consequences. The tracker has indicated that federal organizations such as the FTC and CISA mainly enforce policies.

It claims that government involvement in regulations serves as a “test bed” in which various regulatory strategies can be piloted. The models of risk-tiered systems of Colorado illustrate how innovation and the protection of privacy can be harmonized—namely, through less stringent regulations of low-risk applications of AI and tighter regulations of high-risk applications of AI.

White & Case is a leading international law firm with direct AI regulatory practice experience. The source goes into granular analysis of risk-based state laws, including specific provisions

of the Colorado AI Act and California bills. It clearly explains the federal versus state regulatory division—a key feature of U.S. AI governance. However, it, as a legal practice tracker, focuses more on providing information about compliance rules rather than conducting a detailed study regarding whether rules based on risk have a real bearing on matters of privacy, nor does it measure investment impacts of a state's rules based on risk. Furthermore, despite having localized systems of regulations and standards, there remains a problem of coordination between federal and state or local governments in compliance with these regulations.

This information provides immediate applicability to our current analysis on the application of United States risk-based frameworks. The Colorado AI Act provides information on the regulation of tier-based risk regulation to illustrate the creation of specific rules for the regulation of information rather than regulation of the same in general terms.

2.2 Theme 2: Privacy problem in the U.S. framework

i. Source 3: Governance of Generative AI (Taeihagh, 2025)

This peer-reviewed article attempts to investigate the governance issue that has been termed the “pacing problem,” which is the large gap between evolving generative AI technology and the rather slow pace of legal regulation. Taeihagh has pinpointed different governance mechanisms, such as adaptive governance—the modification of regulation with evolving AI technologies, participatory governance—the incorporation of both AI developers and the privacy community, and proactive governance—predicting risks before they emerge. Taeihagh argues that the current risk-based regulation in the US has focused its regulatory mechanisms only on the risks involved with AI deployment but fails to recognize the current risks involving AI training data. Taeihagh argues that the pacing problem makes traditional regulation ineffective for generative AI, requiring more flexible and anticipatory approaches.

It also argues that the U.S. risk-based frameworks remain incomplete by not considering data privacy during training—a clear omission, as generative AI is typically trained on vast datasets collected without consent. The author believes in participatory governance, with the inclusion of privacy stakeholders, for effective balancing between innovation and data protection.

An article recently published in *Policy and Society*—a leading international policy studies journal—offers a theoretical analysis of the pacing problem within risk-based regulation and zeroes in on generative AI, the fastest-growing and most investment-intensive sector of AI in the United States. However, the article is more theoretical and does not contain actual empirical data regarding the U.S.'s risk systems themselves. There are no actual cases showing how state or federal regulators are engaging in adaptive governance systems that they have created or implemented in various fields or industries.

This source highlights a critical gap that our hypothesis lacks regarding our understanding of whether these risk-based systems effectively cover all AI privacy and related risks, such as those involved with training data. The adaptive governance framework highlights solutions that might address these gaps without impeding innovation, which is highly related to our research question.

ii. Source 4: Training AI on Personal Data Scraped from the Web (IAPP, 2023)

This article from IAPP discusses the legal challenges facing web-scraped training data for AI systems. It chronicles active U.S. lawsuits against AI companies, which include *PM v. OpenAI*

LP, a class action case in California accusing the company of gathering the personal information of hundreds of millions of internet users without permission. The article compares the U.S. approach with that of the EU: whereas the GDPR in the EU requires explicit consent for personal data processing, U.S. law depends on gray areas like "fair use." The Italian Data Protection Authority imposed a €20 million fine on Clearview AI after the latter was found to have scraped biometric data from the web. The article says that U.S. risk-based regulations do not consider web scraping for AI training a regulated high-risk activity, leaving privacy associated with the training data in a state of insufficient protection.

Accordingly, the article proposes the notion that the legal ambiguity in the United States with respect to 'web scraping' poses notable gaps with respect to the privacy of training data for AI. Unlike the 'GDPR,' where consent for data protection is clearly established, the current legal scenario in the United States fails to address the dynamics of 'private rights in training data.' Therefore, these legal nuances result in the varied practices adopted by industries to either refrain from 'web scraping,' as the regulatory scenarios are ambiguous, or use the situation to their advantage by exploiting the loopholes for efficient 'web scraping.'

It is published by IAPP, the leading global authority on the practice of privacy. This source utilizes real U.S. case law—such as *PM v. OpenAI LP* and *Clearview AI*—to give examples of actual privacy violations. The U.S.-EU comparison shows the paradigm that the U.S. maintains in terms of privacy standards juxtaposed against international benchmarks. The focus on training data addresses a high-risk area that is largely unregulated. However, the article solely deals in detail specifically with web scraping; it has not addressed other issues regarding data privacy in AI in a detailed manner. Similarly, it has addressed gaps in the law pertaining to a certain matter, while it has not addressed other laws of individual states regarding risks in detail. Further, it has not specifically discussed how such gaps in the law can affect investments in AI.

This information is highly relevant to our hypothesis as it directly challenges our statement that America has "strong enough" privacy regulations and goes as far as to show us that our regulations on some important aspects of AI innovation, namely the use of training data, are not only weak but still unresolved as part of our risk-based regulations. It also serves to reinforce an important disparity in our regulatory flexibility and the lack thereof regarding concerns over privacy during AI development activities.

2.3 Theme 3: EU & China framework

- i. Source 5: AI Act: Regulatory framework for artificial intelligence (European Commission, 2024)

The EU AI Act, passed in 2024, sets out the world's first comprehensive regulatory principles for AI systems, with categories including unacceptable risk AI (prohibited, including social scoring and mass surveillance), high-risk AI (stringent rules apply to employment, healthcare, and education-related applications), limited risk AI (transparency obligations are applied), and minimal risk AI (no rules are applied). High-risk AI systems shall perform conformity assessments, maintain documentation, and apply human oversight. It combines GDPR rules (when personal data is used, consent must be obtained), including rules to provide a legal basis for the processing of personal data in AI training sets. Penalties are up to 7 percent of global turnover or €35 million.

The European Commission believes that the AI Act strikes a balance between stimulating innovation in AI and protecting fundamental rights. Because of its risk-based approach, low-risk applications can enjoy great flexibility, while stringent oversight is applied to high-risk uses. Integration with GDPR ensures the data privacy of training data that is left unregulated under U.S. frameworks.

As the official EU regulatory source, this provides authoritative documentation of the world's most comprehensive AI framework. The risk-based classification system offers a clear model for comparison with U.S. state-level methods. Furthermore, this shows how privacy protection can be built into AI governance. However, as an official government source, it presents the framework favourably without a critical assessment of potential innovation impacts. Additionally, it extends only to 2027, so empirical outcomes remain unavailable.

This source is essential for comparative analysis. The EU's comprehensive federal approach contrasts with U.S. fragmentation and weak training data regulation. This comparison helps evaluate whether the U.S. or the EU better achieves a balance between development and privacy protection.

ii. Source 6: Global AI governance law and policy: China (IAPP, 2025)

This IAPP resource analyses China's AI governance framework from a privacy perspective. It has three main laws in the framework structure: the Cybersecurity Law, the Data Security Law, and the Personal Information Protection Law. China's generative AI measures require providers to use data from legitimate sources with proper consent, conduct security assessments, and align content with core socialist values. The resource notes that China divides data into two categories: important data and core data.

IAPP argues that China's framework creates clear obligations for AI developers regarding training data consent and security, contrasting with U.S. ambiguity on web scraping.

IAPP is the leading global privacy authority, which means it provides authoritative analysis. The resource clearly explains the integration of the Cybersecurity Law, Data Security Law, and Personal Information Protection Law with AI-specific regulations, offering comprehensive coverage of China's approach. However, it solely focuses on the legal framework rather than empirical outcomes, indicating a limited discussion of effectiveness.

This source enables comparative analysis between the U.S. AI framework and China's AI framework. This helps evaluate whether the U.S. or China better achieves a balance between development and privacy protection.

3. Hypothesis

"A risk-based AI regulation system in the U.S., which sets different rules depending on the type of AI, will likely attract more investment in AI development, but on the other hand, will still keep data privacy standards strong enough."

This hypothesis can be evaluated through the following analytical framework: Investment Proposition, Privacy Protection Proposition, and Balance Proposition. This draws on

regulatory state theory, where risk-based approaches calibrate compliance burdens to hazards, promoting innovation without blanket restrictions.

This hypothesis is based on the following premise: regulatory design plays a decisive role in shaping investment behavior and privacy outcomes in the field of artificial intelligence. A risk-based AI regulatory regime is expected to create differentiated incentives by treating AI applications according to their varying potential risks. According to this hypothesis, developers and investors are far more likely to respond positively to a regime that eschews one-size-fits-all regulation and instead provides flexibility for lower-risk AI technologies.

The hypothesis further posits that investment and data privacy are not inherently opposing objectives. Rather than viewing stricter regulation as an inevitable barrier to innovation, it proposes that targeted regulation can protect personal data without imposing unnecessary restrictions on the AI industry. In this sense, the anticipated growth in AI investment stems not from the weakening of regulation, but from its clarity and appropriateness. Finally, the hypothesis implies that there exists a balance where innovation-friendly policies and robust privacy safeguards can coexist within a single regulatory framework.

If a risk-based regime functions as intended, it should reduce regulatory barriers to AI development while providing adequate protection for sensitive data. This forms the core argument that this paper sets out to examine.

4. Methodology

This study adopts a comparative qualitative research methodology to examine risk-based AI regulatory approaches in the U.S., the EU, and China. The analysis focuses on three dimensions: whether the system promotes the development of AI, whether the system effectively protects individuals' privacy, and whether a balance is achieved between innovation and privacy protection. These questions are examined through the evaluation of regulatory structures, policy objectives, and real-world outcomes across different regions. Primary sources such as official regulations and policy documents, as well as secondary sources including academic articles and expert analyses, are used to support the evaluation.

Evidence is qualitatively coded from regulatory texts and triangulated with empirical data (e.g., investment figures, lawsuits). Cases are selected as most-different systems: the U.S. (market-led, fragmented), the EU (rights-led, unified), and China (state-led centralized).

This research relies solely on publicly available information and does not involve human subjects. While the analysis aims to remain objective, evaluating regulatory effectiveness might involve value judgments. Therefore, this study seeks to present a balanced assessment of the trade-offs between innovation and privacy protection.

5. Results

The following tables present comparative findings across the three evaluation dimensions, drawn directly from the reviewed sources. The ratings reflect the strengths or levels of each aspect based on available evidence.

Does the system promote AI development?

	U.S. Approach	EU Approach	China Approach
Regulatory flexibility	High	Mid	Low
Investment trends	Investment from individuals	Slow	Government-based investment
Impact on startups	Favourable	Challenging	Mixed

Sources: European Commission (2024), IAPP (2025), Stanford Institute for Human-Centered Artificial Intelligence (2025) and White & Case LLP (2025)

Does the system effectively protect privacy?

	U.S. Approach	EU Approach	China Approach
Training data regulation	Weak (no consent)	Strong (GDPR integration)	Medium (Consent is required)
Enforcement	Not strong (state-level)	Strong	Strong

Sources: European Commission (2024), IAPP (2023) and IAPP (2025)

Did they balance between privacy and innovation?

	U.S. Approach	EU Approach	China Approach
Overall balance	Leans toward innovation	Leans toward privacy	Leans toward state control
Regulation style	flexible	Strict	Directive
Real world effects	Fast AI growth	Slower AI growth, but safer	Government-led progress (generally fast)

Sources: European Commission (2024), IAPP (2025) and White & Case LLP (2025)

The tables present a comparative analysis of the U.S., EU, and China's approaches concerning AI development, privacy protection, and the balance between privacy and innovation.

In the first table, under "Promotion of AI development," "Regulatory flexibility" has a high, mid, and low rating, respectively, for the U.S., EU, and China approaches. This refers to the extent to which regulations in these regions are conducive to AI technology development. The U.S. has a high level of flexibility (White & Case LLP, 2025), which means its regulations are not too rigid or inhibiting, creating a conducive environment for AI technology development, which is rapid in this region. The EU has a mid-level flexibility (European Commission, 2024), which means there is a balance but with a bit of caution in AI technology development, while China has a low level (IAPP, 2025), which means its regulations are inhibiting, slowing down AI technology development in this region.

"Investment trends" shows individual investments in the U.S., slow investments in the EU, and government investments in China, which refers to the sources of funding for AI technology development in these regions. While investments are individual in the U.S. (Stanford Institute for Human-Centered Artificial Intelligence, 2025), slow in the EU, and government-based in China (IAPP, 2025), "Impact on startups" is positive in the U.S. (White & Case LLP, 2025; European Commission, 2024; IAPP, 2025), negative in the EU, and mixed in China, which refers to how startups are viewed in these regions regarding AI technology development support.

The second table evaluates how well the system safeguards privacy. "Training data regulation" is weak in the U.S. approach (IAPP, 2023), strong in the EU approach, and medium in the China approach (IAPP, 2025). This is because of the legal systems that regulate the use of data in training AI models, with the EU having the strongest laws in this regard via GDPR

(European Commission, 2024), the U.S. having weak laws, and China having laws that are in between.

"Enforcement" is not strong at the state level in the U.S., strong in the EU, and strong in China. This is because of the effectiveness and strength of the privacy laws being enforced and maintained in each of these regions. The EU has strong enforcement (European Commission, 2024) to ensure that it adheres to its tough privacy laws, and the U.S. does not have strong enforcement at the state level (White & Case LLP, 2025), while China has strong enforcement (IAPP, 2025).

The third table deals with the question of whether there is a balance between privacy and innovation. "Overall balance" reflects an approach leaning towards innovation in the U.S. approach, leaning towards privacy in the EU approach, and leaning towards state control in the China approach. This reflects the main concern or priority in each region's approach to balancing the relationship between privacy and innovation. Innovation is prioritized in the U.S. approach (Stanford Institute for Human-Centered Artificial Intelligence, 2025), privacy is prioritized in the EU approach (European Commission, 2024), and state control is prioritized in the China approach (IAPP, 2025).

Similarly, "regulation style" is flexible in the U.S. approach, strict in the EU approach, and directive in the China approach. While the U.S.'s flexible style accommodates greater experimentation and adaptation, the EU's strict style guarantees high privacy protection, and the Chinese directive style is characterized by government initiatives. "Real-world effects" illustrate the rapid growth of AI in the U.S. (Stanford Institute for Human-Centered Artificial Intelligence, 2025), slower and safer AI growth in the EU (European Commission, 2024), and government-led AI growth in China (IAPP, 2025). These "effects" illustrate the consequences and trade-offs of the approaches taken in the U.S., EU, and China to balance privacy and AI growth. The U.S. balances rapid AI growth with the cost of privacy (Stanford Institute for Human-Centered Artificial Intelligence, 2025), the EU balances AI growth with the need for safety, and China balances AI growth with government control.

6. Discussion

Our hypothesis stated that "A risk-based AI regulation system in the U.S., which sets different rules depending on the type of AI, will likely attract more investment in AI development, but on the other hand, still keep data privacy standards strong enough."

According to the comparative analysis provided in the results section, our hypothesis is partially confirmed as follows: First, the U.S. risk-based system has successfully sustained AI investment leadership with \$109.1 billion in private investment in 2024; second, the flexibility of the regulatory system at the state level has provided a good condition for startups and innovation; third, the decentralized system provides an opportunity to try different approaches in the regulation system.

However, as indicated in the results section, there are some aspects of our hypothesis that were not confirmed: First, the current U.S. system does not provide "good enough" privacy protection, as indicated by the 56.4% increase in AI-related incidents in 2024; second, the current system does not provide "good enough" regulation of training data, as there is no

federal consent required for web scraping; third, there is a lack of consistency in enforcement with fragmented state-level agencies.

As a result, while the U.S. risk-based system succeeds in sustaining AI investment leadership and promoting AI development, it does not provide “good enough” privacy standards as indicated in our hypothesis.

The results reveal a fundamental imbalance in the U.S. approach. As shown in Table 3, the U.S. approach leans toward innovation rather than an actual balance between development and privacy. This is a trade-off between development and privacy, which prioritizes economic development more than the individual’s privacy. However, the EU’s approach leans toward more privacy, which leads to slower AI development. China’s system leans toward government-led control, achieving rapid development in AI but raising concerns about political oversight and transparency. None of the three frameworks achieve an optimal balance.

Additionally, one of the main problems mentioned in the analysis is about privacy protection. Epoch AI predicts that high-quality training data will become scarce between 2026 and 2032. As data becomes scarce, AI companies will face pressure to collect more data through aggressive methods like web scraping.

The current risk-based framework in the U.S. does not anticipate this behavior driven by scarcity. As shown in Table 2, U.S. training data regulations are weak without a consent requirement. This implies that privacy violations are likely to increase rather than decrease as resource constraints intensify, supported by the indicator of the 56.4% rise in AI incidents.

In contrast, the EU’s GDPR integration addresses this concern by requiring consent for data. China’s consent requirement also provides protection of personal data, though it is unclear how strictly China enforces these rules in practice.

This analysis of the three regions provides improvement points for the U.S. approach. To reach a balance between AI development and privacy, the U.S.’s AI regulation might need to combine the following improvement points.

Firstly, the establishment of a federal-level privacy standard is needed for AI training data. Such a standard would reduce the regulatory gap between states by setting minimum requirements for each state, while still allowing states to adopt stricter rules if desired.

Secondly, greater transparency in training data practices should be required. Just like the transparency requirements stipulated in the EU framework, AI developers may be mandated to reveal their sources of data and the methods used in collecting it. In this way, accountability and trust will be enhanced.

Thirdly, the framework should strengthen consent mechanisms for personal data used in AI training. By requiring either explicit consent for personal data or clearly defining legitimate interest, this would help address the regulatory gaps identified in Table 2 within the current U.S. system.

Fourth, an integrated enforcement mechanism is required to ensure consistency. This can be done through the creation of a special AI regulation agency or through enhanced coordination among existing bodies such as state-level regulatory authorities.

There are several limitations in our research analysis. The following limitations exist. First, there are limitations inherent in qualitative research methodology. The analysis in this study aims to provide policy insights through comparison rather than to prove a quantitatively verifiable causal relationship between different regulatory approaches and their outcomes.

Second, the rapidly changing AI regulatory landscape may affect the sustained validity of the research findings. For example, the EU AI Act has its implementation timeline extended in phases until 2027, and in the U.S., state-level AI and privacy legislation continues to proliferate, meaning some of this study's findings may require revision over time.

Third, constraints on data availability exist. Comprehensive and reliable data on AI-related privacy incidents are limited, particularly in China where transparency regarding enforcement processes and incident disclosure is low. Furthermore, the cited 56.4% increase in incidents potentially carries interpretive limitations, as it encompasses not only personal data breaches but various types of AI-related incidents.

Fourth, structural complexity across jurisdictions acts as a limitation for comparative analysis. The federalist system in the U.S., the supranational governance of the EU, and China's centralized regulatory model possess fundamental political and regulatory differences, making direct comparisons and drawing generalized conclusions inherently challenging.

7. Conclusion

In this study, the level of balance between accelerating AI development and data privacy protection within the U.S. risk-based AI system, given global resource constraints, was investigated. From the comparative analysis, it was established that the U.S. system supports accelerating AI development and sustaining high private-investment levels, that the EU system supports data privacy protection but slows down AI development, and that the Chinese system supports accelerating AI development despite government transparency issues. In essence, the hypothesis was partially confirmed since the U.S. system supports AI investments but does not provide sufficient data privacy protection.

From the comparative analysis, differences in the regulations were noted. In the U.S. system, there is an emphasis placed on innovation, which makes the nation the global leader in AI investment, with private investment reaching \$109.1 billion in 2024, mainly due to the flexible regulations at the state level. In the EU system, the unified regulations ensure robust data privacy, but at the expense of slower AI development. In the Chinese system, the centralized regulations ensure the rapid development of AI by the government, but with the potential for transparency issues. None of the three systems ensures an optimal balance between innovation and data privacy.

To improve the policy deficiencies identified in the current United States risk-based framework, several policy recommendations have been made. These include the development of federal baseline privacy policies for AI system training data to alleviate state-level regulatory issues while still allowing for flexibility, the requirement for transparency in AI system training data sources and collection methods, the strengthening of consent policies for the utilization of personal information in AI system training data, and the development of a unified enforcement system through a dedicated AI system regulatory body or through increased interagency

collaboration among existing authorities. Moreover, the framework should actively mitigate possible resource-related issues through the inclusion of protective measures against practices such as unregulated web scraping.

The qualitative approach of this study does not allow for quantifiable causal relationships to be established between regulatory approaches and outcomes. The constantly changing regulatory environment of AI, including phased rollouts of the EU AI Act and increasing state laws in the U.S., could impact the overall validity of these results in the future. Quantitative analysis could be used in future studies to quantify the impact of regulations, as well as sector-specific studies to improve risk-based frameworks.

Ultimately, this study highlights the fact that effective AI governance is about more than just an innovative regulatory environment. Rather, it is about achieving an effective and sustainable balance between the development of AI and data privacy, as well as an adaptive, unified, and forward-thinking regulatory environment, particularly as global data constraints continue to increase the need for effective data collection.

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9. Appendix

Appendix A: Comparative Regulatory Framework Summary

Region	Regulatory Structure	Training Data Privacy	Overall balance
Unite States	State-level	Weak (no consent requirement)	Leans toward innovation
European Union	Unified	Strong (GDPR integration, consent required)	Leans toward privacy
China	Centralized	Medium (Consent required)	Leans toward state control

Sources: European Commission (2024), IAPP (2025), IAPP (2023) and White & Case LLP (2025)

Appendix B: AI investment and incident data

Indicator	Value	Source
U.S. private AI investment,2024	\$109.1 billion	Stanford HAI AI Index Report, 2025
Increase in AI-related incidents,2024	56.4%	Stanford HAI AI Index Report, 2025
High-quality training data exhaustion	2026~2032	Epoch AI; Villalobos et al., 2024
EU AI act maximum penalty	7% turnover or €35M	European Commission, 2024

Analyzing Uncertainty and Inflation Forecasting: A Bayesian State-Space Model Approach

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1. Introduction

From the mid-1980s to 2019, many developed economies, especially the United States, experienced a decades-long period of macroeconomic stability. Their inflation rates remained low for a long time with minimal volatility, and economic growth was relatively stable. Under this environment, traditional inflation prediction models, such as ARIMA and the Phillips curve model, were successful. All these models rely on a stable economic structure. However, since 2020, the impact of the COVID-19 pandemic has disrupted the world's economic development. For instance, epidemic prevention lockdowns, factory shutdowns, and port congestion have led to unprecedented disruptions in the global supply chain. Economic policy has also undergone a fundamental shift from loose to tight. In the new environment, the parameters of traditional models are fixed and cannot adapt to the fluctuations in the economic structure. They may also overlook factors such as uncertainty.

However, when the economic structure is frequently impacted, this assumption has already failed. Bayesian UCM enables the model to continuously learn through the Bayesian update mechanism. With the arrival of each new data point, the model's understanding of potential states (trends, cycles) and key parameters is dynamically updated, thereby adjusting the prediction of future paths in real time. For example, it can identify the rise in the trend inflation level or the change in the persistence of the shock. Therefore, the model proposed in this study not only offers more abundant structural insights, but also serves as an important tool for the timeliness of the model in response to the current highly uncertain environment.

Therefore, a model that can rigorously predict uncertainty and dynamically adapt is needed to predict inflation. The UCM model is a time series statistical model that decomposes an observed time series into multiple latent components with clear interpretations, which are not directly observable, and uniformly models, estimates, and forecasts these components within a state-space framework. The UCM model is a core subclass of the Bayesian state-space model. The UCM model can solve the problems that occur in the above-mentioned traditional models. For instance, when the economy undergoes structural fluctuations, the UCM model can adapt well to these changes because it can model the trend components as random walks or random walks with time-varying drift. In this way, they are not fixed and can change with the data. Moreover, when an economic shock occurs, it can adjust the trend to a new level.

The research subject of this study focuses on the U.S. economy. The data studied ranges from 2000 to 2023, which comprehensively covers multiple structural shocks such as the dot-com

bubble, the global financial crisis, and the COVID-19 pandemic. It is a suitable sample for predicting inflation. This study uses data from the United States to verify uncertainty and the model's advantages over traditional models. The predictions of this model can also provide risk warnings.

2. Literature Review

In traditional models, they each have their own advantages and functions. For instance, in the ARIMA model, it can play a significant role in univariate statistical extrapolation. It serves as the benchmark method for predicting time series based on the historical values of inflation itself. The econometric models used to forecast inflation are ARIMA (Autoregressive Integrated Moving Average) and VAR (Vector Autoregression), which are both time series models. ARIMA models use a combination of autoregressive (AR) and moving average (MA) components to model the relationships between a dependent variable and its past values and error terms (van der Plas, 2023). In the vector autoregressive model, its function is a multivariable dynamic system. It places inflation in a multivariable (GDP, interest rate, unemployment rate) system, capturing the mutual dynamic influences among the variables. VAR models, on the other hand, are used to model the joint behavior of multiple dependent variables. They assume that each variable is linearly dependent on its own past values, as well as the past values of other variables in the system. VAR models are particularly useful for modeling the dynamics of economic systems, where multiple variables influence each other (van der Plas, 2023).

However, in the ever-changing environment, the traditional models ARIMA and VAR have gradually revealed their drawbacks in application. The shortcomings of ARIMA mainly manifest in three aspects: Firstly, it can only be used for prediction based on historical data of a single variable. ARIMA fails to capture the bursty and non-linear behavior of CPU usage. Forecasts were often overly smooth and failed to anticipate critical usage spikes (Le Duc et al., 2025). The second methodology has limitations. The model does not directly analyze inflation data but relies on inflation differential processing, for example, calculating the rate of change to satisfy the stationarity assumption. After calculation, the prediction result still needs to be restored to the inflation level value. During the restoration process, errors are inevitable. The longer the time, the greater the error, making the final prediction result inaccurate. The flexibility and timeliness of the third model are insufficient. The core parameters and the order of inflation difference are usually fixed, making it difficult to quickly adapt to unexpected events. ARIMA can only rely on historical data for slow adjustment, and the prediction results are seriously lagging and lack timeliness.

There are also many drawbacks in the VAR model. Firstly, the VAR model can only handle observable variables such as GDP and the unemployment rate. It is difficult to apply to unobservable variables such as policy expectations and market confidence. However, these factors are precisely the key ones influencing inflation. If one attempts to combine these factors through a state space model, it will lead to a sharp increase in the number of parameters. This not only requires a large amount of historical data for support but also easily results in unstable and unreliable prediction outcomes. Standard VAR can only contain a very limited number of variables due to excessive parameters (the curse of dimensionality); otherwise, it will lead to a serious loss of degrees of freedom and estimation problems

(Bernanke et al., 2005). Secondly, the model has a situation where the number of parameters increases exponentially with the increase in the number of variables and the lag order. Under limited data, the model responds sluggishly to new shocks, ultimately causing the prediction results to lag behind.

As a major method for estimating core inflation, there are still two deficiencies in the application of state space models to date. Firstly, the traditional estimation method of the state space is the maximum likelihood estimation based on Kalman filtering. However, this estimation method has a significant drawback, namely that the estimation of state variables depends on other parameters. Specifically, first obtain the maximum likelihood estimates of the unknown parameters, and then assume that these parameters are non-random, that is, assume that their maximum likelihood estimates are their true values. However, this contradicts the assumptions of the state space model. Secondly, we construct fan charts that describe the uncertainty surrounding future inflation by taking into account diverse sources of uncertainty that include a form of model uncertainty (Cogley et al., 2003). However, in the practical application process, the limitations of traditional models have gradually emerged, specifically manifested as insufficient adaptability, inability to fully consider the uncertainty of external shocks, and difficulty in effectively splitting the sources of complex fluctuations, among other issues.

It is worth noting that the UCM model (Non-observed Component Model) in BSM (Bayesian Structured Time Series Model) can precisely fill the gap left by traditional models. This model can not only solve the problem that traditional models find it difficult to split the sources of complex fluctuations, but also breaks through the limitation of single data dimensions of traditional models, thereby improving the problem of insufficient adaptability. Therefore, it can be flexibly applied to various emergencies, such as epidemics, economic crises, and other situations.

The UCM model can effectively address the limitations of VAR and ARIMA. Compared with ARIMA, its advantage is that it can directly analyze the inflation level value without the need for differential calculation to satisfy stationarity assumptions, avoiding the information loss problem of traditional models. It can clearly break down inflation into several components, such as trend components, cyclical components, seasonal components, and irregular components, which are separable potential components. The structural time-series model represents the components of a time series, which are its trend, its cyclical components, and its seasonal components (Pollock, 2010). It can accurately identify short-term fluctuation characteristics and discover long-term patterns of inflation. It also avoids the parameter explosion problem that occurs when extending factor-augmented VAR. It can integrate observable and unobservable variables for prediction, perfectly making up for the shortcomings of VAR. The model decomposes each of the four coincident variables into a common component, which is interpreted as the 'state of the economy,' and an idiosyncratic component. This framework allows us to estimate the common component using the Kalman filter (Zarnowitz, 1991). In addition, under the Bayesian framework, the UCM model can set time-varying parameters or stochastic volatility. The model can automatically adapt to the fluctuations in the data, learn new changes, and has stronger stability and the ability to keep up with reality and update in real time compared to the fixed-parameter VAR and ARIMA models when dealing with sudden major events such as financial crises and epidemics in different eras. By allowing for time-varying parameters or stochastic volatility, the UCM can continuously update its understanding of the economic state, effectively capturing the

evolution of the data-generating process, which grants it a critical advantage during periods of structural instability (Koop & Korobilis, 2013).

By leveraging the limitations of traditional models and the advantages of UCM, this paper assesses the performance of Bayesian UCM in inflation prediction and uncertainty quantification, making a contribution to the existing literature. The main research hypothesis is that the prediction results generated by Bayesian UCM can be comparable to those of traditional models such as ARIMA and VAR, even if not superior. We also hypothesize that UCM outperforms these traditional models in characterizing prediction uncertainty, enabling more reliable and accurate inflation predictions.

3. Methodology

Overview of Model Construction, Data, and Methodological Revision

This study selects the model (UCM) as the center-oriented model, and uses the models VAR and ARIMA as the reference benchmark models. UCM can analyze the trend and cyclical components of economic variables, and capture the dynamic correlation between the inflation rate and core indicators (M2 money supply, GDP). The correlation between them is stronger than the growth. Its prediction accuracy is comparable to that of the VAR and ARIMA models. This study will run the UCM model using the provided STATA code, based on the relevant dataset from 1923 to 2023, to predict the relevant data for 2023 to 2025, and compare the prediction results with the output results of the reference models to verify the effectiveness of the UCM model.

The dependent variable of this study is the inflation rate. This indicator is measured by the City Consumer Price Index (CPI-U) released by the U.S. Bureau of Labor Statistics (BLS), and is used to calculate the annual changes in the U.S. price level from 1923 to 2025. This data is highly consistent and easily accessible, and is the mainstream benchmark indicator in the field of inflation research.

The independent variables are economic indicators, including M2 money supply and gross domestic product (GDP).

The dataset of this study includes historical data of M2, GDP, and the inflation rate from 1923 to 2023, as well as predicted data generated based on the UCM model from 2023 to 2025. All the data come from a single source, thus conforming to the principle of a single variable. The dataset has undergone consistency processing, including uniform statistical frequencies, to ensure the reliability of the modeling and prediction results.

4. Findings

4.1 Analysis of the output results of the Unobservable Component Model

This output presents the estimation results of the Unobservable Components Model (UCM). The UCM is a powerful method for time series analysis. It can break down the time series into interpretable unobserved components.

Unobserved-components model

Components: local linear trend, order 1 cycle

Sample: 1994 thru 2023

Number of obs = 30

Wald chi2(4) = 288.20

Log likelihood = -47.223407

Prob > chi2 = 0.0000

inf	Coefficient	Robust std. err.	z	P> z	[95% conf. interval]	
cycle1						
frequency	1.411788	.1597732	8.84	0.000	1.098639	1.724938
damping	.8610407	.1356658	6.35	0.000	.5951407	1.126941
inf						
gdp_g	.3992259	.1594969	2.50	0.012	.0866178	.7118341
m2_g	.2080165	.0899328	2.31	0.021	.0317514	.3842815
var(level)	.3516933	.3661598	0.96	0.168	0	1.069353
var(slope)	.0071986	.0277646	0.26	0.398	0	.0616163
var(cycle1)	.2005534	.1560748	1.28	0.099	0	.5064544
var(inf)	.1363815	.1351564	1.01	0.156	0	.4012831

Note: Model is not stationary.

Note: Tests of variances against zero are one sided, and the two-sided confidence intervals are truncated at zero.

Figure 1. The results of the general linear model

In this analysis, the model is set to include a local linear trend and a first-order periodic component. The sample period is from 1993 to 2023, with a total of 30 observations. The core dependent variable is the inflation rate, and the model also has two key macroeconomic explanatory variables: GDP growth rate and the growth rate of M2 money supply.

First, the overall performance of the model is evaluated based on the log-likelihood value, which is -47.223407. This value itself cannot be directly interpreted, but it serves as the basis for the Wald chi-square test, which is used to determine the joint significance of all the parameters of the model.

The Wald test statistic is 288.20 (with a degree of freedom of 4), and the corresponding p-value is 0.0000, while the conventional significance level is 0.05. This result indicates that the model as a whole is statistically significant. Our hypothesis is to reject the "all coefficients being zero simultaneously," so the trend, cycle, and regression terms can effectively explain the changes in the inflation rate within the sample period.

4.2 Cycle component analysis

The first-order periodic component of the UCM is described by two core parameters: frequency and damping coefficient. The estimated value of the frequency is 1.411788, and the robust

standard error is 0.1597732. This indicates that the relevant periodic process completes approximately 1.41 cycles per year, corresponding to a period length of approximately 8.5 months (calculated as $12/1.41$).

The estimated value of the damping coefficient is 0.8610407, and the robust standard error is 0.1356658. The damping coefficient lies between 0 and 1, indicating that this cycle is stable. Its fluctuations will gradually diminish over time, rather than experiencing explosive growth or a sudden decrease.

Both of these parameters have a high degree of statistical significance. The statistical values of the two parameters are 8.84 and 6.35, respectively, with p-values both being 0.000. This confirms the existence of significant and stable cyclical fluctuations in the inflation data, reflecting the short-term fluctuations of inflation around the long-term trend, and demonstrating a cyclical nature.

4.3 Regression coefficients of the inflation equation

The inflation model quantified the relationship between inflation and observable macroeconomic driving factors. The coefficient of the variable "gdp_g" was 0.3992259, the robust standard error was 0.1594969, the z-statistic was 2.50, and the p-value was 0.012, which was significant at the 5% level.

This means that, when all other conditions remain the same, for every 1% increase in the GDP growth rate, the inflation rate is expected to rise by approximately 0.40%. This is consistent with the conclusion that "an increase in economic activity will push up price pressures."

Similarly, the coefficient of m2_g (M2 growth rate) is 0.2080165, the robust standard error is 0.0899328, the z-statistic is 2.31, and the p-value is 0.021. This indicates that for every 1% increase in M2 growth rate, the inflation rate will rise by approximately 0.21%. This is consistent with the view that "changes in money supply growth are related to changes in price levels."

The variance indicates the volatility of the unobservable components and the model error terms. The variance of the level term ($\text{var}(\text{level})$) is 0.3516933, the robust standard error is 0.3661598, the z-statistic is 0.98, and the p-value is 0.168, fluctuating within the 5% significance range. The variance of the slope term ($\text{var}(\text{slope})$) is 0.0071986, the robust standard error is 0.0277646, the z-statistic is 0.26, and the p-value is 0.398, showing no significant change. The variance of the periodic term ($\text{var}(\text{cycle1})$) is 0.2005534, the robust standard error is 0.1560748, the z-statistic is 1.28, the p-value is 0.099, and it only appears at the 10% level. Finally, the variance of the error term in the inflation equation ($\text{var}(\text{inf})$) is 0.1363815, the robust standard error is 0.1351564, the z-statistic is 1.01, and the p-value is 0.156. Therefore, it is not statistically significant.

In conclusion, summarizing the above changes, this model has conducted a detailed decomposition of the inflation dynamics from 1994 to 2023. The results confirm that there are significant cyclical components in inflation, and there are also significant changes between inflation and GDP growth rate, as well as the M2 growth rate. As GDP and M2 increase, inflation also increases.

The duration is 29 years.

Linear regression		Number of obs	=	29
		F(2, 26)	=	2.88
		Prob > F	=	0.0743
		R-squared	=	0.2328
		Root MSE	=	1.3643

inf	Coefficient	Robust std. err.	t	P> t	[95% conf. interval]	
gdp_g	.3850463	.1607559	2.40	0.024	.0546079	.7154847
m2_g	.1712626	.1120404	1.53	0.138	-.0590398	.4015649
_cons	.4213694	1.041855	0.40	0.689	-1.720193	2.562932

Figure 2. The results of the UCM model

F-test value ($F(2, 26)$): 2.88, and the corresponding P-value (Prob > F) is 0.0743, indicating that the model has a significant decrease of approximately 10%.

Fit goodness (R-squared): 0.2328, indicating that 23.28% of the variation in the dependent variable (inflation rate) is explained by the model.

Root Mean Square Error (Root MSE): 1.3643, which represents the average difference between the predicted values of the model and the actual values.

Economic growth (gdp_g) is a significant factor contributing to the increase in the inflation rate (inf). For every one-unit increase in the GDP growth rate, the inflation rate typically rises by approximately 0.385 units. This is true in all cases.

The impact of the growth in money supply (M2_g) on the inflation rate is positive, but it is not statistically significant. This might be due to the short duration of the sample years, which results in a less noticeable deviation.

5. Discussion

This paper will further analyze the limitations and practical application value of the UCM model's prediction of U.S. inflation and its comparison with traditional models, and will put forward optimization suggestions and core insights.

5.1 Limitations

This study only focuses on the data of the United States from 2000 to 2023 and does not cover other countries, thus lacking universality. Although the third part considers factors such as interest rates, GDP, and oil prices, external factors such as the financial crisis, the Sino-U.S. trade war, the Russia-Ukraine war, weather impacts, and the 2020 pandemic are not included. These factors may disrupt the rhythm of inflation, leading to inaccurate inflation predictions.

The UCM model assumes that complex economic changes can always be clearly divided into several independent parts (such as long-term trends and short-term cycles) and accurately measured, but its explanatory power is insufficient and lacks in-depth insight into the structural causes and persistence behind trends and cycles. Although the unobserved component model can adapt to inflation changes after sudden shocks to some extent by incorporating new data, this adaptability is passive, and its core feature is that it performs better in predicting during periods of inflation volatility, but less effectively during normal periods of stable inflation.

5.2 Application Value

The UCM model has wide applications in both policy and business fields. In terms of policy, the UCM model can be used to assess the short-term and temporary shocks to current inflation pressure, thereby providing a basis for the formulation of monetary policy. In the business field, it can also be used to predict the trends of market demand and user behavior changes, providing effective support for business decision-making and operational optimization.

5.3 Future Optimization Suggestions

To enhance the usability and popularity of the UCM model, it is recommended to promote its tooling and ease of use. The academic community should collaborate with software developers to develop graphical interfaces or standardized code packages to simplify the model operation process and lower the threshold for using the UCM model. On the other hand, further efforts should be made to lower the application threshold of the model, making it accessible to users without a professional background and thereby expanding its promotion scope.

6. Conclusion

This study applies the Bayesian Unobserved Components Model (UCM) to the prediction of U.S. inflation and the quantification of uncertainty, using ARIMA and VAR models as benchmark models. The literature review indicates that traditional models have limitations: ARIMA is constrained by single-variable dependence and fixed parameters, VAR models face the problem of the curse of dimensionality, and traditional state-space models have estimation method flaws and insufficient economic interpretability. In contrast, the UCM model has significant advantages in these aspects. It can decompose data into latent components, directly analyze inflation data, update parameters dynamically, and integrate observable and unobservable variables for prediction.

This study selects U.S. data from 2000 to 2023 as the research sample (covering multiple structural shocks such as the 2008 U.S. economic crisis), measures inflation levels with the Urban Consumer Price Index (CPI-U), and takes M2 and GDP as core variables. After consistency processing of the 1993–2023 data, a UCM model with a local linear trend and a first-order cyclical component is constructed for the 1993–2023 data through STATA software, and the inflation trend from 2023 to 2025 is predicted. The empirical results verify the overall statistical significance of the UCM model, revealing a stable 8.5-month cycle in U.S. inflation, and significant positive impacts of GDP and M2 growth rates on inflation (for every 1% increase in each, inflation rises by approximately 0.40% and 0.21%, respectively). However,

most variance estimates of the model are not significant, and there are non-stationary characteristics.

This study has limitations, such as only covering U.S. data and lacking universality, and not including external shock factors. However, it has high application value in policy and business. In the future, it can be further optimized by reducing the usage threshold through tool development. The model's ability to capture long-term trends and enhance interpretability is superior to traditional models, but this does not mean it replaces traditional models; rather, it is a complementary and effective supplement. Since the model does not include external shock factors, it is prone to prediction deviations at historical turning points. In the future, external shock models and the coupling mechanism of micro-behavior models can be incorporated to enhance the model's adaptability in complex environments.

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The Construction of Resilient Cities in the Yangtze River Delta under a Volatile Global Environment

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Abstract

At a time when the background of globalization is increasingly volatile and the uncertainty of climate change and economic growth is increasing, improving urban resilience has become the core issue for ensuring sustainable development. This research focuses on the Yangtze River Delta region, which has the highest level of urbanization and is the most economically active in China, aiming to explore the key driving factors and construction paths of its ecological and economic resilience.

The study selected three core cities, Shanghai, Nanjing and Hangzhou, as samples, and built a comprehensive urban resilience index (URI) based on panel data from 2015 to 2024. Objective weighting was carried out through the entropy weight method, and a multivariate fixed-effect regression model was used to empirically analyze the economic and ecological variables affecting resilience.

The study found that for economic resilience, the integrity of the industrial structure, the foreign trade vitality of private enterprises and the per capita disposable income of residents are the key driving forces, which are far more important than simple GDP growth. In terms of ecological resilience, the traditional ecological concept of "static stability" may have limitations, and it should be replaced by the ability of "dynamic recovery". Third, there is significant heterogeneity in urban resilience, which requires that governance strategies be adapted to local conditions.

Based on this, this paper puts forward policy proposals shifting from a "GDP-only" orientation to structural optimization, from static stability management to dynamic recovery monitoring, and conceptualizes an "economic-ecological" resilience governance framework for cross-city coordination. This study provides a quantitative basis and differentiated governance ideas for the construction of resilient cities in the Yangtze River Delta and other similar areas.

Keywords

Yangtze River Delta region; resilient city; economic resilience; ecological resilience; collaborative governance

1. Introduction

In recent years, the global situation has become more and more volatile. At the ecological level, global climate change is intensifying, and the impact on human beings is becoming more and more significant. At the economic level, global economic growth is expected to slow down, and inflation is falling from a high level, and major economies are facing various challenges. Against this background, how to resist the impact of urban ecological and economic risks and achieve adjustment, adaptation, and rapid recovery has become one of the research hotspots in the field of smart city construction.

"Resilient City" refers to the urban form in which cities can independently resist disasters, reduce disaster losses, and quickly recover from disasters through the reasonable allocation of resources. Comprehensively promoting the construction of resilient cities is an objective requirement to meet the current situation of urban security development. It is also an important part of promoting the modernization of urban governance, which can effectively enhance the people's sense of gain, happiness and security. By the end of 2024, China has clearly proposed building a number of high-level resilient cities by 2030, which will be listed as one of the eleven key tasks.

With the acceleration of China's new urbanization process, the problem of urban resilience has become more and more prominent. In recent years, the academic community has carried out a series of useful explorations on this topic, covering the concept of resilient cities, evaluation systems, evaluation methods and other aspects. In the domestic literature, Li Tongyue (2014) defined the urban resilience index and diagnosed urban resilience; Liu Jiangyan and Zeng Zhongping (2014) built an urban resilience evaluation index system and carried out empirical research; Zhai Guofang (2015) explained the application background of resilient urban construction standards from multiple perspectives. In foreign literature, the Rockefeller Foundation describes the resilient urban framework through performance indicators; Jabareen Y (2013) explores the components of urban resilience, namely infrastructure resilience, institutional resilience, economic resilience and social resilience; Franchin P and Cavalieri F (2014) proposed a framework map of urban infrastructure resilience and explained its main characteristics. The research area is the Yangtze River Delta region, which covers 27 central cities in three provinces and one city. Only 2% of the country's land area contributes 20% of the gross national product. It has strong ecological response ability and economic recovery ability in terms of the ecological environment and economic development.

This article tries to explore the construction plan of resilient cities and its advantages in dealing with disasters from the dual perspective of ecological resilience and economic resilience. First of all, this study sorts out the existing research on resilience construction around the world and seeks theoretical support; secondly, it finds the key factors affecting urban resilience through the calculation of resilience coefficients and regression model research; finally, policy suggestions are put forward based on the existing conclusions to enable resilience city construction to expand to many types of cities to achieve cross-urban differentiated linkage development. The research results of this article can provide a basis for the construction of resilient cities in the Yangtze River Delta region, and also provide new perspectives and strategies for the construction of resilient cities nationwide.

2. Review

i. Core definition

The core connotation of a resilient city is that the urban system has the ability to resist, adapt, quickly recover and transform and upgrade in the face of natural disasters, public health events, economic fluctuations and other internal and external disturbances (Holling, 1973). Resilient cities at the regional level also emphasize the synergy within urban clusters, covering the four core dimensions of engineering resilience (infrastructure risk resistance), social resilience (community governance), economic resilience (industrial impact resistance and transformation vitality), and ecological resilience (ecosystem resistance and resilience) (Zhang et al., 2023). The dynamic cycle of disturbance-response-recovery-upgrade is recognized as the essential feature of resilient cities.

ii. Research significance

As one of the urban clusters with the highest level of urbanization and the most active economy in China, the Yangtze River Delta region faces multiple challenges such as frequent meteorological disasters (e.g., floods and typhoons), excessive population concentration, and high pressure on public health emergency prevention and control. Improving urban resilience is the inevitable choice to ensure the sustainable development of the region (Li & Wang, 2022). The exploration of the construction of resilient cities in the Yangtze River Delta can enrich the localized theoretical system of urban resilience and provide replicable experience for the resilience management of China's high-density urban clusters. The national "14th Five-Year Plan" clearly puts forward the goal of improving the resilience level of urban flood control and drainage, as well as disaster prevention and mitigation. As a national strategic region, the Yangtze River Delta plays a leading and exemplary role in the construction of national resilient cities (National Development and Reform Commission, 2021).

iii. Existing theories and research priorities

The existing research mainly revolves around three theories: first, complex system theory, which regards cities as complex systems composed of population, economy, infrastructure and other subsystems, and emphasizes the impact of the coupling relationship between subsystems on urban resilience (Mancini et al., 2020); second, risk management theory, which focuses on the identification, evaluation and prevention of disaster risks, and provides methodological guidance for the construction of a resilient city index system (Taleb, 2007); and third, the theory of collaborative governance, which advocates that the government, market and multiple social subjects should jointly participate in the construction of resilient cities and clarify the powers and responsibilities of each subject boundary (Ansel & Gash, 2008). For the Yangtze River Delta region, researchers have measured the resilience level of core cities and generally have come to the conclusion that "the resilience level of core cities is higher than that of surrounding cities, and regional resilience varies significantly" (Zhang et al., 2023). The current research views mainly focus on three aspects: improving the infrastructure network, promoting the upgrading of industrial structure, and strengthening cross-regional collaborative governance (Zhou & Liu, 2022).

iv. Research gaps

At present, the construction of localized theory is insufficient. Most studies directly apply the Western resilient city theoretical framework, which fails to fully combine the regional governance characteristics of "strong government and strong market" in the Yangtze River Delta, lacks a theoretical model of resilience adapted to high-density urban clusters, and the quantitative exploration of standards for economic, ecological and other resilience mechanisms is not deep enough (Sun, 2023). At the same time, there is a lack of tracking of the changes in long-term resilience construction in the Yangtze River Delta region, which fails to reveal the long-term evolutionary law of urban resilience; the research on the cross-regional coordinated governance mechanism is weak, and the existing research focuses on a single city, and there is insufficient discussion on issues such as internal joint prevention and control, resource sharing and policy coordination within the Yangtze River Delta urban cluster (Xie, 2023). In addition, the relevant exploration of the cultivation of resilience awareness and long-term security mechanisms at the social level is also relatively lacking.

v. The value of this study

This article focuses on the two core levels of ecology and economic resilience, establishes a clear and targeted research direction, which meets the core needs of urban risk management under the current global turmoil, and selects economic and ecological data from the past ten years to explore the long-term development of resilient cities and build a quantitative index system. In terms of theoretical foundation, it systematically sorts out the literature related to resilient cities at home and abroad and lays a comprehensive and rigorous theoretical foundation for subsequent analysis; the research horizon will eventually expand to many types of cities, and its results are expected to provide reference for other parts of China, helping various places quickly take countermeasures in the event of major disasters and improve urban recovery ability.

3. Methodology

3.1 Introduction

This chapter aims to explain the research design and methods in detail and clarify the research problems and main objectives to ensure the scientificity and repeatability of the research.

3.2 Research design

This research aims to analyze the construction and results of ecological resilience and economic resilience in the Yangtze River Delta region, and explore the promotion of this resilience model in other regions, focusing on the combination of theoretical analysis and practical problem solving. This paper calculates the toughness coefficient by consulting the data, finds the variables affecting the toughness coefficient, and constructs a functional model for quantitative analysis.

3.3 Sampling

Regional sample: Three core cities in the Yangtze River Delta (Shanghai, Nanjing, and Hangzhou) were selected, and the selection was based on their high economic density, concentrated urban population, and their exposure to representative risk challenges such as floods, typhoons, and public health emergencies.

3.4 Data collection

The data collection was conducted through the analysis of the relevant data of cities from 2015 to 2024 provided by the Shanghai Municipal Bureau of Statistics and the Statistical Communiqué, the Hangzhou Municipal Bureau of Statistics and the Environmental Bureau, and the Nanjing Municipal Bureau of Statistics, covering the two major aspects of ecology and economy, involving many aspects such as urban GDP and urban green space coverage. The data cover ten years up to 2024. Fifteen core documents related to the resilience of the Yangtze River Delta from 1973 to 2024 were collected from China Knowledge Network, Web of Science, and other databases, covering conceptual definitions, index systems, empirical evaluation, and other research topics. In addition, the government's official website was also used to collect national resilience city policies from 2015 to 2024 to study resilient city construction.

3.5 Data Analysis

The research uses the toughness index as the main indicator. The Urban Resilience Index (URI) is a quantitative, multi-dimensional comprehensive evaluation index system used to measure the ability of urban systems to maintain their own structural stability, quickly recover, and achieve adaptive development in the face of internal and external disturbances.

The calculation of the urban resilience index needs to follow the four-step process of index system construction → indicator standardization → weight assignment → comprehensive index synthesis.

i. Construction of the index system

Based on the four-dimensional model of "ecological, economic, social, and infrastructure" resilient cities of the United Nations Habitat, combined with the development characteristics of the study region, representative underlying indicators are screened (see the table below).

ii. Standardization of indicators

Due to the differences in the metric framework and magnitude of different indicators (for example, "per capita GDP" is in 10,000 yuan, and "sewage treatment rate" is in percentage units), it is necessary to eliminate the influence of the quantitative framework through standardization so that the index values are comparable. Two standardized methods are used in the research:

- a) Standardization of positive indicators (the larger the index value, the stronger the resilience, such as the per capita green space area)

$$X'_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)}$$

Among them, X_{ij} is the original value of the j -th indicator of the i -th city, and the maximum and minimum values of the j -th indicator in all research cities, respectively, used for standardization, and the value range is $[0,1]$.

b) Standardization of negative indicators (the larger the index value, the weaker the resilience, such as energy consumption per unit of GDP)

$$X'_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)}$$

After standardization, all indicators are converted into positive indicators. The closer the value is to 1, the greater the contribution to resilience.

- c) Indicator weight assignment: The weight is determined based on the discreteness of the original data of the indicator (entropy weight method). The higher the degree of discreteness of the index, the stronger the distinction between toughness and the greater the weight.
- d) The weighted summation method is used to calculate the comprehensive resilience index of each city.

$$URI_i = \sum_{j=1}^m W_j \times X'_{ij}$$

Among them, URI_i is the resilience index value of the i -th city, and the value range is $[0,1]$. The closer the value is to 1, the stronger the urban resilience; the closer the value is to 0, the weaker the urban resilience.

Table 1: Calculation of the Resilience Index for Hangzhou, Nanjing, and Shanghai in 2024

Criterion Layer	Indicator Layer	Indicator Nature	Indicator Weight	Raw Data	Yangtze River Delta Reference Range	Standardized Value	Weighted Score
Economic Resilience (0.28)	Per Capita GDP (10,000RMB)	Positive	0.07	18.3	12.5-25.0	0.827	0.0579
	Tertiary Industry Proportion(%)	Positive	0.07	64.1	55.0-80.0	0.700	0.0490
	Growth Rate of Industrial Revenue of Above-scale Enterprises(%)	Positive	0.07	4.5	0.5-6.0	0.750	0.0525
	Number of High-tech Enterprises (units)	Positive	0.07	13,500	8000-25000	0.857	0.0600
Social Resilience (0.25)	Number of Hospital Beds per 10,000 people (units)	Positive	0.0625	66.8	50.0-85.0	0.574	0.0359
	Urban Registered Unemployment Rate(%)	Negative	0.0625	2.1	1.8-3.5	0.824	0.0515
	Basic Medical Insurance Coverage Rate(%)	Positive	0.0625	99.9	95.0-100.0	0.980	0.0613
	Number of Public Transport Vehicles per 10,000 people (units)	Positive	0.0625	23.5	15.0-35.0	0.567	0.0354
Infrastructure Resilience (0.22)	Urban Gas Pipelization Rate(%)	Positive	0.0733	99.9	95.0-100.0	0.980	0.0718
	Urban Sewage Treatment Rate(%)	Positive	0.0733	98.7	90.0-99.5	0.967	0.0699
	5G Base Station Coverage Rate(%)	Positive	0.0734	95.2	80.0-98.0	0.933	0.0685
Ecological Resilience (0.25)	Green Coverage Rate in Built-up Areas(%)	Positive	0.0833	44.3	35.0-50.0	0.620	0.0516
	Proportion of Days with Excellent Air Quality(%)	Positive	0.0833	86.1	75.0-95.0	0.555	0.0462
	Surface Water Compliance Rate(%)	Positive	0.0834	95.5	85.0-99.5	0.817	0.0682
Total Standardized Value						0.778	

Criterion Layer	Indicator Layer	Indicator Nature	Indicator Weight	Raw Data	Yangtze River Delta Reference Range	Standardized Value	Weighted Score
Economic Resilience (0.28)	Per Capita GDP (10,000RMB)	Positive	0.07	17.8	12.5-25.0	0.773	0.0541
	Tertiary Industry Proportion(%)	Positive	0.07	61.5	55.0-80.0	0.522	0.0365
	Growth Rate of Industrial Revenue of Above-scale Enterprises(%)	Positive	0.07	3.8	0.5-6.0	0.591	0.0414
	Number of High-tech Enterprises (units)	Positive	0.07	12,800	8000-25000	0.773	0.0541
Social Resilience (0.25)	Number of Hospital Beds per 10,000 people (units)	Positive	0.0625	67.2	50.0-85.0	0.591	0.0369
	Urban Registered Unemployment Rate(%)	Negative	0.0625	2.2	1.8-3.5	0.783	0.0489
	Basic Medical Insurance Coverage Rate(%)	Positive	0.0625	99.7	95.0-100.0	0.940	0.0588
	Number of Public Transport Vehicles per 10,000 people (units)	Positive	0.0625	21.8	15.0-35.0	0.453	0.0283
Infrastructure Resilience (0.22)	Urban Gas Prpularization Rate(%)	Positive	0.0733	99.8	95.0-100.0	0.960	0.0703
	Urban Sewage Treatment Rate(%)	Positive	0.0733	98.2	90.0-99.5	0.911	0.0668
	5G Base Station Coverage Rate(%)	Positive	0.0734	93.5	80.0-98.0	0.810	0.0595
	Green Coverage Rate in Built-up Areas(%)	Positive	0.0833	43.8	35.0-50.0	0.576	0.0479
Ecological Resilience (0.25)	Proportion of Days with Excellent Air Quality(%)	Positive	0.0833	84.5	75.0-95.0	0.475	0.0395
	Surface Water Compliance Rate(%)	Positive	0.0834	94.2	85.0-99.5	0.650	0.0822
	Total Standardized Value					0.697	

Criterion Layer	Indicator Layer	Indicator Nature	Indicator Weight	Raw Data	Yangtze River Delta Reference Range	Standardized Value	Weighted Score
Economic Resilience (0.28)	Per Capita GDP (10,000RMB)	Positive	0.07	23.1	12.5-25.0	0.840	0.0588
	Tertiary Industry Proportion(%)	Positive	0.07	78.2	55.0-80.0	0.992	0.0645
	Growth Rate of Industrial Revenue of Above-scale Enterprises(%)	Positive	0.07	5.1	0.5-6.0	0.898	0.0629
	Number of High-tech Enterprises (units)	Positive	0.07	22,000	8000-25000	0.952	0.0666
Social Resilience (0.25)	Number of Hospital Beds per 10,000 people (units)	Positive	0.0625	76.8	50.0-85.0	0.797	0.0498
	Urban Registered Unemployment Rate(%)	Negative	0.0625	3.0	1.8-3.5	0.400	0.0250
	Basic Medical Insurance Coverage Rate(%)	Positive	0.0625	99.9	95.0-100.0	0.980	0.0613
	Number of Public Transport Vehicles per 10,000 people (units)	Positive	0.0625	31.5	15.0-35.0	0.883	0.0552
Infrastructure Resilience (0.22)	Urban Gas Prpularization Rate(%)	Positive	0.0733	100.0	95.0-100.0	1.000	0.0733
	Urban Sewage Treatment Rate(%)	Positive	0.0733	99.5	90.0-99.5	1.000	0.0733
	5G Base Station Coverage Rate(%)	Positive	0.0734	98.0	80.0-98.0	1.000	0.0734
	Green Coverage Rate in Built-up Areas(%)	Positive	0.0833	40.2	35.0-50.0	0.347	0.0289
Ecological Resilience (0.25)	Proportion of Days with Excellent Air Quality(%)	Positive	0.0833	88.5	75.0-95.0	0.823	0.0686
	Surface Water Compliance Rate(%)	Positive	0.0834	99.3	85.0-99.5	0.986	0.0822
	Total Standardized Value					0.8125	

(In sequence, they are respectively the information of Hangzhou, Nanjing, and Shanghai in 2024.)

In addition, the research data come from the Government Statistical Yearbook, Government Work Report, and public documents.

The study selected five variables in terms of economy and ecology, respectively. Economic variables include: GDP, per capita disposable income, unemployment rate, the combined industrial proportion of the three major industries, and the proportion of private enterprises in foreign trade. GDP and per capita disposable income can reflect the capital reserves and economic buffering capacity of cities and are the material foundation of resilient cities; the unemployment rate reflects the resilience of the labor market; the total industrial proportion of the three major industries reflects the support ability and impact resilience of the real economy; the foreign trade proportion of private enterprises can reflect the diversification of market entities and vitality. Ecological variables are: the degree of green transformation of large-scale industrial enterprises, resource recycling utilization rate, vegetation resilience coefficient, bird stability index, and the control rate of invasive alien species. The utilization rate of resource recycling reflects the degree of risk of resource shortage; the vegetation resilience coefficient can reflect the resilience of the ecosystem under emergencies; the control rate of alien invasive species and the bird stability index can reflect the living space and stability of native organisms. By investigating the changes in these data between 2015 and 2024 and analyzing the degree of impact of each variable on the resilience coefficient, the study finds out the most

critical variables for the coefficient, so as to analyze the impact of emergencies on urban resilience and the trend of resilience construction in these three cities over the past ten years.

4. Findings

4.1 Model setting and variable description

Based on the analytical framework of resilient cities, this study constructs a multivariate fixed-effects regression model with time as the dependent variable and explores the evolutionary characteristics of urban resilience from the two dimensions of economy and ecology. Economic variables cover GDP, per capita income, unemployment rate, the total proportion of the three major industries, and the proportion of foreign trade of private enterprises. Ecological variables include green transformation, resource recycling, vegetation resilience, bird stability, and invasive species control rate, aiming to reveal the dynamic changes of urban resilience systems in different stages of development and their dynamic mechanism.

4.2 Analysis of empirical results (economic variables)

The model takes the economic resilience index as the explained variable, the economic dimension-related variables as the explanatory variables, and the city as the control variable. The R^2 of the two models is 0.935 and 0.993, respectively, indicating that the model has a strong explanatory power for the economic resilience index. After adding industrial structure, foreign trade structure, and urban fixed effect, the R^2 of model 2 is further improved, reflecting the important impact of these new variables on economic resilience.

Per capita disposable income is significantly positive ($p < 0.01$) in both models, and the coefficient is between 1.57×10^{-6} and 5.00×10^{-6} . This shows that the improvement of residents' income level is a stable core factor for enhancing economic resilience. Income growth can improve residents' consumption capacity and risk resistance, thus supporting economic resilience.

The GDP scale is negative but not significant in model 1, and significantly positive in model 2 ($p < 0.01$). It shows that when only the scale of the economy is considered, its impact on resilience is unstable; when industrial and urban characteristics are added, GDP growth shows a positive effect, reflecting that the resilience effect of economic scale depends on supporting conditions such as industrial structure.

The total proportion coefficient of the three major industries is 0.00946 ($p < 0.01$) and is significantly positive, indicating that the integrity of the industrial structure (the coordinated development of the three industries) can effectively improve economic resilience, and the diversified industrial layout can reduce the impact of single-industry fluctuations on the overall economy.

The proportion coefficient of private enterprises in foreign trade is 0.000662 ($p < 0.01$) and is significantly positive, indicating that the higher the participation of private enterprises in foreign

trade, the stronger the economic resilience. The flexibility and market characteristics of private enterprises can enhance risk resistance in the field of foreign trade.

The unemployment rate is not significant in both models, indicating that the direct impact of unemployment rate fluctuations on economic resilience in the short term is weak, and economic resilience depends more on long-term structural factors than on short-term unemployment shocks.

The urban fixed-effect coefficient is positive but not significant, indicating that the inherent characteristics of different cities (such as policies and locations) have a certain positive effect on resilience, but statistically there is no strong significance, and it is necessary to further subdivide city-type verification.

Table2: Regression Analysis Results of Influencing Factors of Economic Resilience Index

VARIABLES	model 1	model 2
GDP	-1.02e-06	8.04e-07
	(3.03e-07)	(3.68e-07)
income	5.00e-06	1.57e-06
	(2.90e-07)	(3.23e-07)
unemployment	--	0.00195
	--	(0.00383)
industry prop	--	0.00946
	--	(0.00151)
private trade	--	0.000662
	--	(0.000220)
constant	-0.159	-0.0802
	(0.0138)	(0.0285)
observations	30	30
city	3	3
R-squared	0.935	0.993

Standard errors in parentheses

***p<0.01,**p<0.05,*p<0.1

Revelations:

- i. Structural optimization is more crucial than overall growth. The results of Model 2 indicate that the impact coefficients of the industrial structure and the private economy (e.g., 0.00946) far exceed those of GDP (8.04×10^{-7}). This suggests that promoting industrial synergy and supporting private foreign trade enterprises play a more significant role in enhancing economic resilience compared to solely pursuing GDP growth.
- ii. Income levels form the foundation of resilience. The sustained positive impact of per capita disposable income suggests that enhancing consumer spending capacity and wealth accumulation is an essential path to strengthening a city's economic resilience to shocks.
- iii. Acknowledge the unique characteristics of individual cities. The significance of urban control variables implies that, when formulating policies, tailored resilience-enhancement strategies must be devised based on the distinctive features of different cities, such as their industrial bases and the vitality of their private economies.

4.3 Analysis of empirical results (ecological variables)

The model takes the ecological toughness index as the explained variable, the ecological-dimension-related variables as the explanatory variables, and the city as the control variable. The R^2 of the model is 0.998, which shows that the model has strong explanatory power for the ecological toughness index and has a good fit.

The degree coefficient of green transformation of large industrial enterprises is 0.00998 ($p < 0.01$) and is significantly positive, indicating that the green transformation of industrial enterprises can significantly improve the ecological resilience of cities. The low-carbon and clean development of industries can directly reduce environmental pressure and enhance the stability of the ecosystem.

The resource recycling utilization coefficient is 0.0144 ($p < 0.05$) and is significantly positive, reflecting that the improvement of resource recycling efficiency can effectively enhance ecological resilience. This mechanism reduces the burden on the ecosystem by reducing resource consumption and waste emissions.

The control rate coefficient of invasive species is 0.00607 ($p < 0.1$) and is significantly positive, indicating that the prevention and control of invasive species can maintain the structure and function of the local ecosystem, thus improving ecological resilience.

The coefficient of vegetation toughness is -0.228 ($p < 0.01$) and is significantly negative. This result is contrary to theoretical expectations. It may reflect that the improvement of vegetation toughness is accompanied by increased competition within the ecosystem, or that the recovery of local vegetation has a short-term inhibitory effect on other ecological elements, which needs to be further combined with the ecological mechanism for verification.

The bird stability index coefficient is -1.620 ($p < 0.01$) and is significantly negative, indicating that the improvement of bird community stability is negatively correlated with ecological resilience. This may be because the excessive stability of birds means that the community structure tends to be single, which reduces the anti-interference ability of the ecosystem.

The urban fixed effect coefficient is -0.0108 ($p < 0.05$) and is significantly negative, reflecting that the inherent characteristics of different cities (such as urban expansion and industrial layout) have an inhibitory effect on ecological resilience. It is necessary to formulate differentiated ecological protection policies for urban heterogeneity.

Table3: Regression Analysis Results of Influencing Factors of Ecological Resilience Index

VARIABLES	
Green transformation	0.00998
	(0.00144)
resource recycle	0.0144
	(0.00722)
vegetation	-0.228
	(0.0447)
bird	-1.620
	(0.448)
alien_ctrl	0.00607
	(0.00360)
Constant	-4,400.450
	9*
	(2,326.440
	7)
Observations	30
Number of city_id	3
R-squared	0.998

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Revelation:

Enhancing ecological resilience requires simultaneous efforts to promote industrial green transitions and biodiversity conservation. Special attention should be given to the long-term

recovery capabilities of vegetation and bird populations, rather than relying solely on short-term stability indicators.

5. Discussion

5.1 Research Limitations

- i. Limitations of samples and indicators: The study only selected 30 groups of observations from three core cities in the Yangtze River Delta. The sample size is small and the coverage is limited, and there are certain limitations to the regional generalization of the conclusion. In addition, this study mainly adopts static cross-sectional data, which cannot fully capture the dynamic evolution characteristics of resilience in the process of impact-recovery.
- ii. Limitations of mechanism analysis: This study focuses on the superficial driving factors of economic and ecological resilience and does not deeply explore the coupling interaction mechanism of the two. This one-dimensional analysis fails to fully present the systematic relationship of urban resilience.

5.2 Real impact and policy inspiration

- i. Economic resilience level: Research confirms that the optimization of industrial structure and the vitality of the private economy are the core supports of economic resilience, which means that local governments should abandon the development orientation of "GDP-only" and shift the policy focus to supporting the foreign trade of private enterprises and promoting the coordinated upgrading of the three major industries. At the same time, continuously improving the disposable income of residents and consolidating consumption-driven resilience can enhance the buffering ability of cities to cope with external shocks.
- ii. Ecological resilience level: The positive role of industrial green transformation and resource recycling shows that the Yangtze River Delta needs to accelerate the construction of a low-carbon recycling industrial system, while the negative effect of the vegetation and bird stability indices suggests that ecological resilience construction should shift from the pursuit of "static stability" to "dynamic recovery" and that there is a need to establish an ecosystem disturbance early warning mechanism and focus on monitoring the long-term recovery ability of the biological community.
- iii. Collaborative governance level: Based on the conclusion of urban heterogeneity, it is recommended that the Yangtze River Delta establish an "economic-ecological resilience" coordinated governance framework. Economically developed cities can focus on the upgrading of industrial resilience, while cities with better ecological endowments should give priority to the protection of biodiversity and achieve the overall improvement of regional resilience through cross-city linkage.

5.3 Future outlook

- i. Carry out research on the adaptation of sub-type cities, adjust the weight of the core driving indicators of economic and ecological resilience for cities with different development characteristics, such as resource-oriented, agricultural-oriented, and

- coastal small and medium-sized cities, and solve the regional heterogeneity of the direct application of Yangtze River Delta experience.
- ii. Combined with dynamic monitoring and impact scenario simulation to promote the implementation of the results, the static driving mechanism of this study should be combined with sudden shock scenarios such as extreme weather and economic fluctuations, to build a dynamic decision-making model for improving resilience for different cities, and to realize the dynamic transformation of research results from theoretical conclusions to urban governance practice.
 - iii. Improve the cross-city collaborative application system of resilience construction and promote the complementary linkage of resilience construction between different cities. For example, economically developed cities can export the experience of industrial upgrading and green transformation to underdeveloped cities. Cities with excellent ecological endowments can provide references for ecological resilience construction for industrial cities, forming a cross-regional and differentiated urban resilience coordination development pattern, and at the same time integrating the research conclusions into policy documents such as urban master planning and ecological environment protection planning, so as to realize the deep integration of theoretical research and policy formulation.
 - iv. Based on the economic-ecological two-dimensional framework of this study, it can be expanded to include social, governance, and other resilience dimensions in the future, extend the research results to the construction of resilient cities in the whole area, provide an empirical basis for different cities to build a multi-dimensional and composite resilience improvement system, and promote the coordinated development of urban resilience construction from a single dimension to a systematic approach.

6. Conclusion

The literature related to resilient cities has formed a basic theory and research framework. Foreign studies focus on framework construction and element definition, whereas China focuses on index diagnosis, evaluation system construction, and so on, with complex system management, risk management, and collaborative governance as the core support.

This research focuses on the construction of resilient cities in the Yangtze River Delta under the background of global turmoil. Taking ecological resilience and economic resilience as the core research dimensions, the three core cities of Shanghai, Nanjing, and Hangzhou are selected. Combined with multiple indicators, and using the entropy weight method and the multivariate fixed-effect regression model, the 2015–2024 phase is systematically analyzed. According to the data, the study explores the key influencing factors and development paths of the construction of resilient cities.

Research shows that in terms of economic resilience, the integrity of the industrial structure, the participation of private enterprises in foreign trade, and the per capita disposable income of residents are the core driving factors, which far exceed the growth of simple GDP scale, and economic resilience depends on long-term structural optimization rather than short-term fluctuations. In terms of ecological resilience, industrial green transformation, capital and the improvement of source recycling utilization, and the prevention and control of alien invasive species can significantly enhance resilience, while the vegetation toughness coefficient and

the bird stability index have an unexpected negative impact, reflecting that the construction of ecological resilience needs to abandon the obsession with "static stability" and shift to the orientation of "dynamic recovery."

At the same time, the study found that the resilience level of the core cities in the Yangtze River Delta is higher than that of the surrounding cities, but there is heterogeneity in the region. The existing research has shortcomings, such as the lack of dynamic monitoring and weak cross-regional collaborative governance research. Based on this, this study puts forward a policy inspiration: it is necessary to abandon the "GDP-only" orientation, focus on industrial collaborative upgrading and private economic support, accelerate the construction of a low-carbon circular industrial system, improve environmental resistance and resilience, build an "economic-ecological resilience" coordinated governance framework, and realize cross-city differentiated linkage development.

This research provides a quantitative basis and practical path for the construction of resilient cities in the Yangtze River Delta. In the future, it can be expanded to multiple types of cities, increase the dynamic monitoring dimension, and improve the cross-regional collaborative application system.

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Research on the Relationship between Educational Fiscal Expenditure and Teaching Quality in Chongqing

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Abstract

Educational fiscal expenditure is the core material guarantee for promoting the improvement of the regional educational level and realizing balanced educational development. Taking Chongqing, which has both an urban-rural dual structure and important national strategic missions, as the research sample, this paper follows the logical line of "theoretical foundation - realistic assessment - empirical test - in-depth problem analysis - countermeasure implementation". It systematically sorts out the development status of urban-rural educational fiscal expenditure and teaching quality in Chongqing, quantitatively analyzes the linkage effect and influence mechanism between them, explores the core problems and causes in the linkage development, and puts forward targeted optimization countermeasures.

The research finds that although the total amount of educational fiscal expenditure in Chongqing has steadily increased, its proportion is relatively low, and the problem of structural imbalance is prominent, with significant investment gaps between urban and rural areas and different regions; the educational level shows regional differentiation characteristics, and the overall coordination degree of linkage between investment and teaching quality is relatively low, and the investment efficiency and driving effect need to be improved.

Based on this, this paper puts forward suggestions from the perspectives of optimizing the investment system, improving the educational level, and building a linkage mechanism, so as to provide a reference for the construction of Chongqing as an education powerhouse city and the balanced and high-quality development of urban-rural education, and also to provide replicable experience for similar regions in the western part of China.

Keywords

Educational Fiscal Expenditure; Educational Gap; Teaching Quality; General High Schools; Chongqing Municipality

1. Introduction

1.1 Research Background

Education is the core driving force for the high-quality development of the regional economy and society, and also a key support for narrowing the urban-rural gap and promoting social equity (Wang, 2010). As a strategic pivot for the development of the western region, a connection point between the "Belt and Road" and the Yangtze River Economic Belt, Chongqing has both the characteristics of an urban-rural dual structure and important national strategic missions, and the development of education occupies a fundamental position in overall regional development. With the in-depth advancement of the Western Development Strategy and the full-scale launch of the construction of an educationally powerful country, Chongqing has taken "building an educationally powerful city" as its goal and regarded the balanced and high-quality development of urban-rural education as the core starting point (Li & Zhang, 2015). As the core material guarantee for educational development, the allocation and use efficiency of educational fiscal expenditure are directly related to the improvement of teaching quality and the effectiveness of building an educationally powerful city, so it is urgent to systematically study the internal correlation between them.

1.2 Research Significance

The adaptability between educational fiscal expenditure and teaching quality is the key to the high-quality development of regional education and the realization of educational equity (Chen & Liu, 2018). Combined with Chongqing's strategic positioning and the actual situation of urban-rural educational development, studying their correlation has important theoretical and practical value, as follows:

1.2.1 Theoretical Significance

Firstly, it enriches the research system of regional educational finance. Existing studies mostly focus on the whole country or eastern regions, while there are few studies on western municipalities directly under the Central Government and regions with both dual structure and strategic positioning. Taking Chongqing as a sample, this study analyzes the linkage mechanism between urban-rural educational fiscal expenditure and teaching quality, filling the research gap in western regions (Zhao, 2012).

Secondly, it deepens the understanding of fiscal expenditure efficiency evaluation. Existing studies have insufficient analysis of the transmission path of "expenditure allocation - fund efficiency - teaching quality". This study focuses on urban-rural heterogeneity, clarifies the differential impact of different types of expenditure on teaching quality, and improves the relevant theoretical framework (Wang, 2010; Sun, 2016).

1.2.2 Practical Significance

Firstly, it addresses the pain points of urban-rural educational development in Chongqing. In view of the current problems in Chongqing, such as uneven urban-rural educational fiscal investment, low expenditure efficiency, and disconnection between investment and quality

(Zhou, 2019; Ma, 2017), this study identifies the core shortcomings through empirical analysis, providing a basis for targetedly solving the gap and improving efficiency.

Secondly, it provides practical suggestions for Chongqing to optimize educational investment. Based on the research conclusions, it puts forward optimization plans from three aspects: total allocation, structural adjustment, and benefit supervision, providing a direct reference for policy formulation by relevant departments and helping the construction of an educationally powerful city (Huang, 2014).

Thirdly, it provides reference for similar regions in the west. Chongqing's urban-rural development characteristics and educational investment dilemmas are representative of the west. The research conclusions can provide replicable experience for other western regions to narrow the urban-rural educational gap and improve the efficiency of fiscal expenditure (Zhao, 2012).

2. Research Ideas and Content

2.1 Research Ideas

Taking the linkage relationship between urban-rural educational fiscal expenditure and teaching quality in Chongqing as the core, this study follows the logical line of "theoretical foundation - realistic assessment - empirical test - in-depth problem analysis - countermeasure implementation" to carry out research work step by step. Firstly, it clarifies the definition of core concepts and the theoretical basis, building a theoretical framework for the whole research (Zhang, 2021; Liu, 2013); secondly, it systematically sorts out the development status of urban-rural educational fiscal expenditure and teaching quality in Chongqing, accurately capturing the characteristics of urban-rural differences between them; thirdly, it quantitatively analyzes the linkage effect and influence mechanism between them through data testing, revealing the action path of fiscal expenditure on teaching quality (Wang, 2011); then, combining the current situation and empirical results, it deeply analyzes the core problems and causes in the linkage development of urban-rural educational fiscal expenditure and teaching quality in Chongqing; finally, it puts forward targeted and operable optimization suggestions based on the causes of the problems, forming a complete research closed loop of "theory - practice - empirical - countermeasure", thereby providing support for the construction of Chongqing as an educational powerful city and the balanced development of urban-rural education.

2.2 Research Content

This study focuses on the "correlation" between educational fiscal investment (from an urban-rural perspective) and educational level in Chongqing, focusing on five core research contents, as follows:

Firstly, the definition of core concepts and the sorting out of the theoretical basis. It defines core concepts such as educational fiscal expenditure (total amount, structure, efficiency) and teaching quality (urban-rural differentiated evaluation dimensions), sorts out relevant theories such as public goods theory (Du, 2015), education equity theory (Chen & Liu, 2018), and fiscal

expenditure efficiency theory (Wang, 2010), clarifies the theoretical logic of the linkage relationship between them, and lays a theoretical foundation for subsequent research (Liu, 2013).

Secondly, the analysis of the current situation and characteristics of educational fiscal expenditure and teaching quality in Chongqing. Combining statistical data, it systematically analyzes the development status of Chongqing's educational fiscal expenditure from the dimensions of total allocation, structural distribution, and regional differences; it judges the development characteristics and urban-rural gaps of Chongqing's teaching quality from core indicators such as teachers' strength, teaching facilities, and educational quality, and initially identifies the realistic performance of the correlation between them (Zhou, 2019).

Thirdly, the measurement of the linkage effect and the analysis of the influence mechanism between educational fiscal expenditure and teaching quality in Chongqing. It selects appropriate indicators and sample data to empirically test the linkage effect of the total amount and structure of educational fiscal expenditure on teaching quality; it further explores the heterogeneous influence mechanism of different types of expenditure (such as teacher investment) and different regions (urban and rural areas) (Sun, 2016; Wang, 2011), and clarifies the core transmission path of the linkage between them.

Fourthly, the analysis of the problems and causes in the linkage development of educational fiscal expenditure and teaching quality in Chongqing. Combining the current situation analysis and empirical results, it focuses on the core problems in the linkage development between them (such as unbalanced urban-rural investment, unreasonable expenditure structure, and low linkage efficiency) (Zhao, 2012; Ma, 2017), it deeply analyzes the fundamental causes of the problems from the aspects of fiscal allocation mechanism, urban-rural development differences, and policy implementation intensity (Huang, 2014; Zhang, 2021).

Fifthly, the countermeasures and suggestions for optimizing Chongqing's educational fiscal investment and strengthening the linkage effect between them. Based on the causes of the problems, combined with the goal of building Chongqing into an educational powerful city and the strategic positioning of the Western Development, it puts forward targeted and practical optimization countermeasures from the aspects of optimizing the total proportion of fiscal expenditure, adjusting the expenditure structure, improving the linkage guarantee mechanism, and narrowing the urban-rural educational gap (Li & Zhang, 2015; Yuan, 2018), helping to improve the coordinated development quality of Chongqing's educational fiscal expenditure efficiency and teaching quality.

3. Definition of Core Concepts

3.1 Educational Investment

The educational investment defined in this study takes fiscal educational expenditure as the core connotation, covering three core dimensions: scale, structure, and efficiency (Liu, 2013): the scale dimension focuses on the total level of educational investment, reflecting the government's financial support for education; the structure dimension focuses on the use distribution of investment (such as teacher investment, scientific research investment) and the

proportion of investment allocation; the efficiency dimension focuses on the use benefit of investment funds, that is, the effect of converting investment into the educational level (Wang, 2010). The research scope is limited to the fiscal educational investment of governments at all levels (municipal, district/county, and town/township) within Chongqing Municipality, and also takes into account the educational investment made by social forces within the municipality (such as enterprise donations, private education investment), with the core focus on fiscal educational expenditure as the main research object.

3.2 Educational Level

Educational level refers to the comprehensive level of regional educational development, whose connotation covers four core dimensions: school-running conditions, teachers' strength, educational output, and human capital stock (Sun, 2016): school-running conditions reflect the hardware foundation of educational development, teachers' strength reflects the core supply capacity of educational services, educational output represents the direct achievements of education (such as enrollment rate, graduation quality), and human capital stock reflects the long-term impact of education on the regional talent reserve (Fan, 2014). This study also distinguishes between the "quantitative level" and "qualitative level" of education: the quantitative level focuses on the scale indicators of educational development (such as the number of schools, the number of students, and the total investment), while the qualitative level focuses on the core effectiveness of education (such as teachers' professional quality, teaching quality, and talent training quality) (Qin, 2020). The analysis mainly focuses on the "qualitative level", taking into account the coordinated development of quantity and quality.

3.3 Linkage Effect

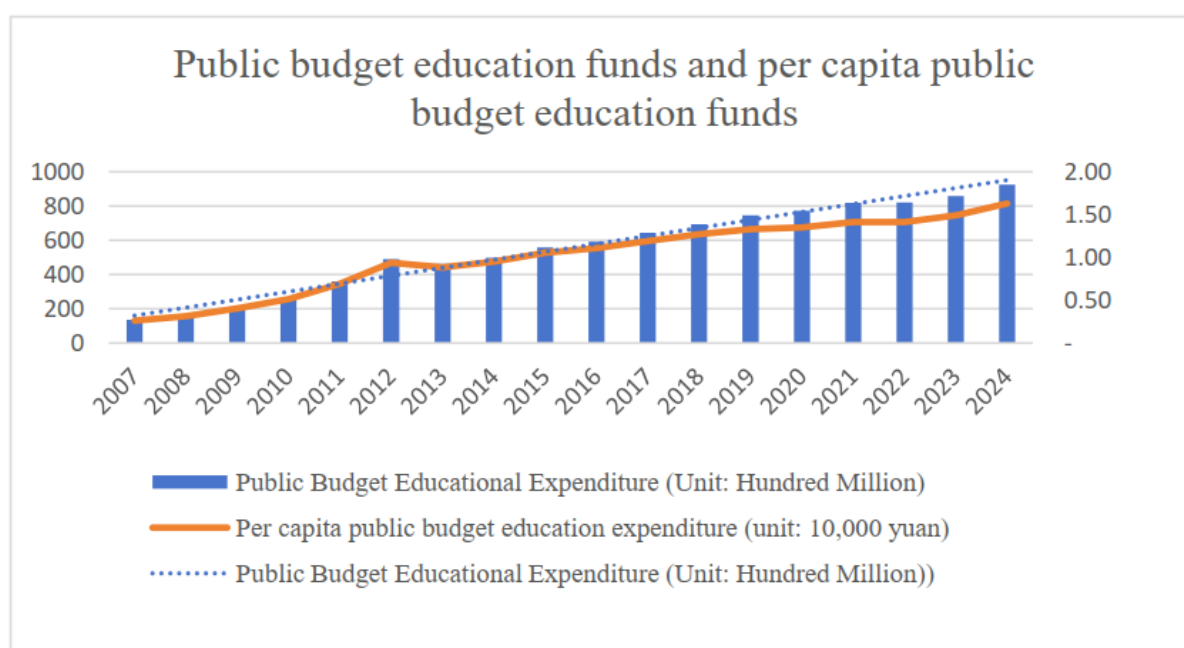
The linkage effect between educational investment and educational level refers to the two-way interaction, mutual influence, and coordinated development relationship between them, rather than a one-way correlation of "investment driving level" (Chu, 2017). Its specific manifestations include three forms: first, the driving effect of investment on the level, that is, the positive promoting effect of educational investment (scale expansion, structural optimization, efficiency improvement) on educational level (school-running conditions, teachers, output, etc.); second, the feedback effect of level on investment, that is, the reverse regulatory effect of the improvement of educational level on educational investment (such as the demand for high-quality education forcing the optimization of investment structure and the improvement of investment efficiency) (Yuan, 2018); third, the coupling and coordination effect between them, that is, educational investment and educational level are mutually adapted and form a virtuous cycle, thereby forming a dynamic balance state of coordinated development (Xie, 2019).

4. Analysis of the Current Situation and Characteristics of Educational Investment and Educational Level in Chongqing

4.1 Current Situation and Characteristics of Educational Investment in Chongqing

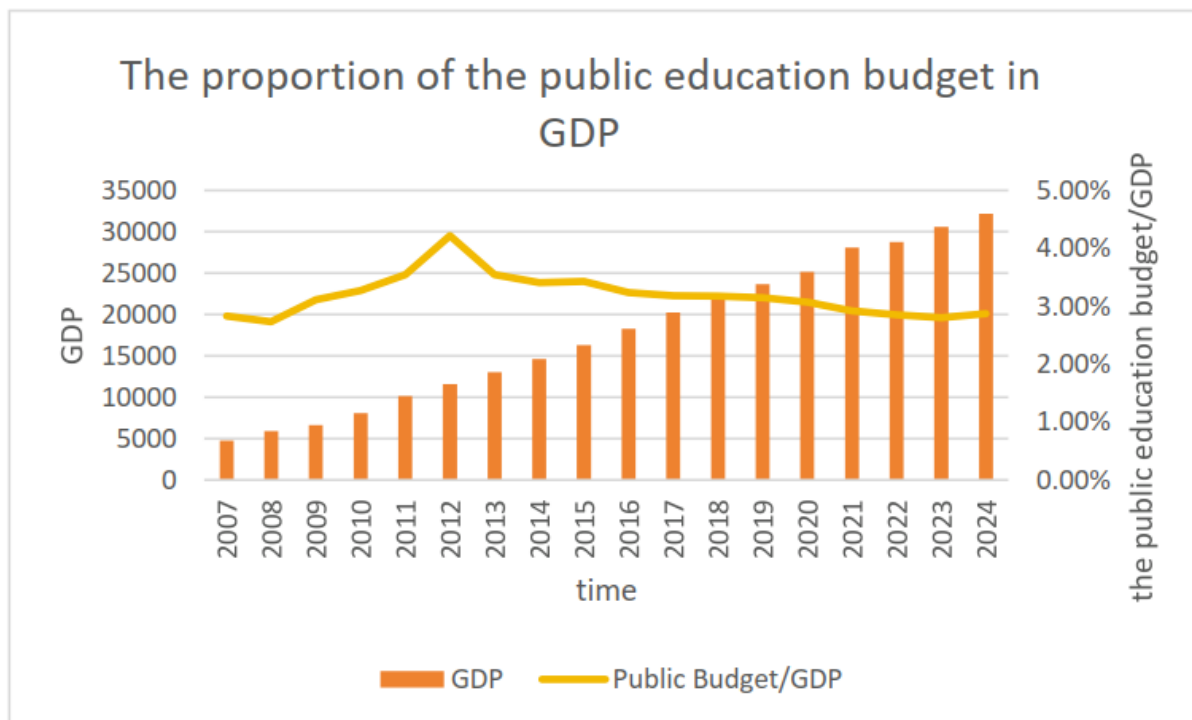
4.1.1 Scale of Educational Investment

The trend over time of the total amount of fiscal educational expenditure (replaced with the public budget for education funds) and per capita fiscal educational expenditure is as follows:



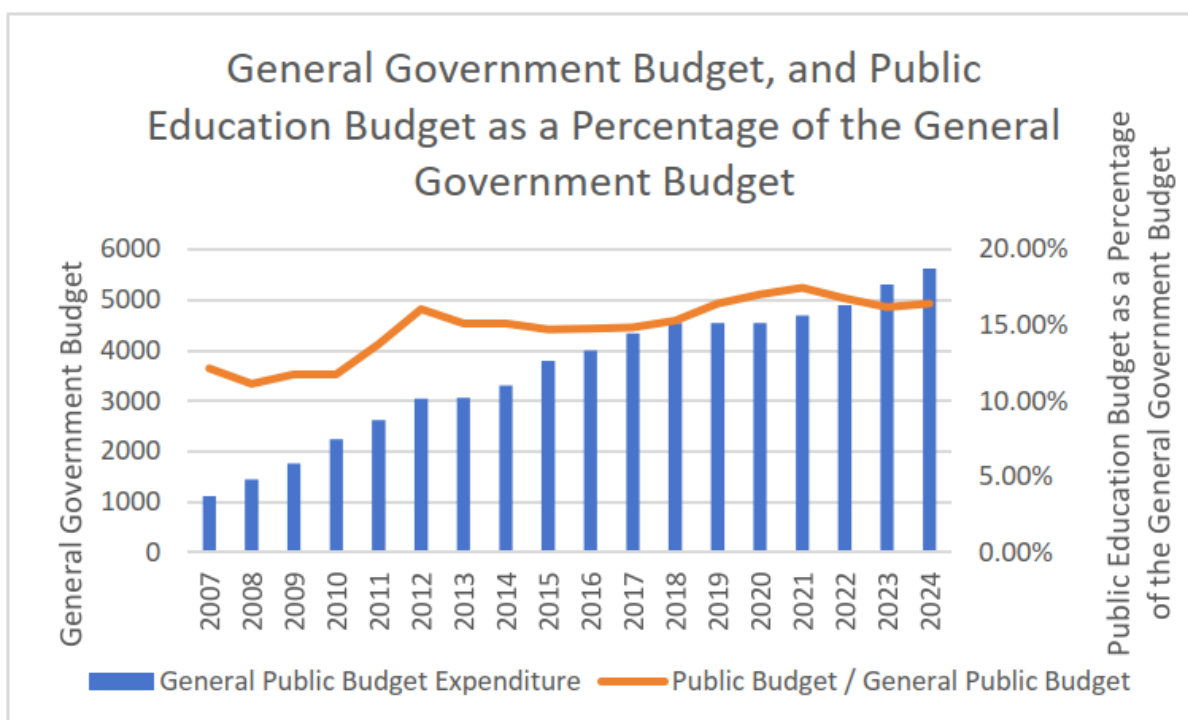
From the perspective of the growth of the public budget for education funds and the per capita public budget for education funds, the public budget for education funds has been in a state of continuous growth in recent years, and the per capita public budget for education funds has also been in a state of continuous growth. However, after 2017, the growth rate of the per capita public budget has been significantly lower than that of the public budget for education funds.

The proportion of educational investment in GDP is as follows:



From the perspective of the proportion of the public education budget in GDP, the proportion of the public education budget in GDP has been continuously decreasing since 2012.

The change in the proportion of the public budget for education funds in the local general public budget expenditure is as follows:

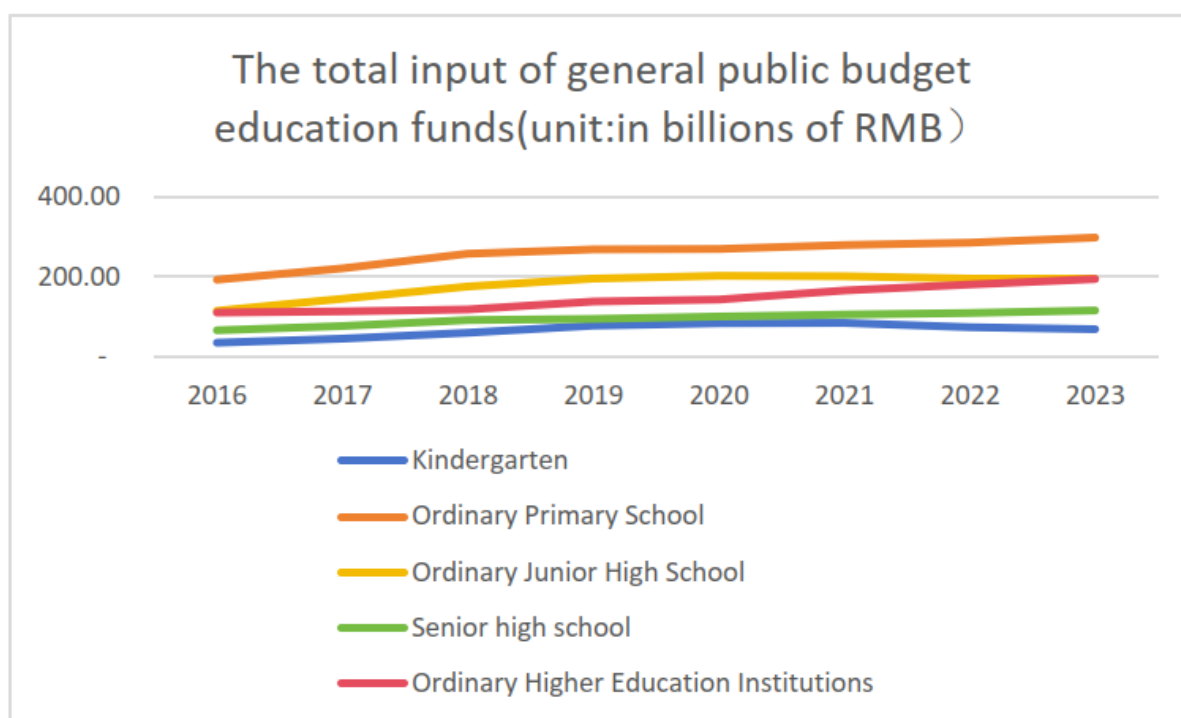


From the data of the general public budget and the public education budget, the proportion of the public education budget in the general public budget has always remained in the range of 15%-20%.

4.1.2 Structure of Educational Investment

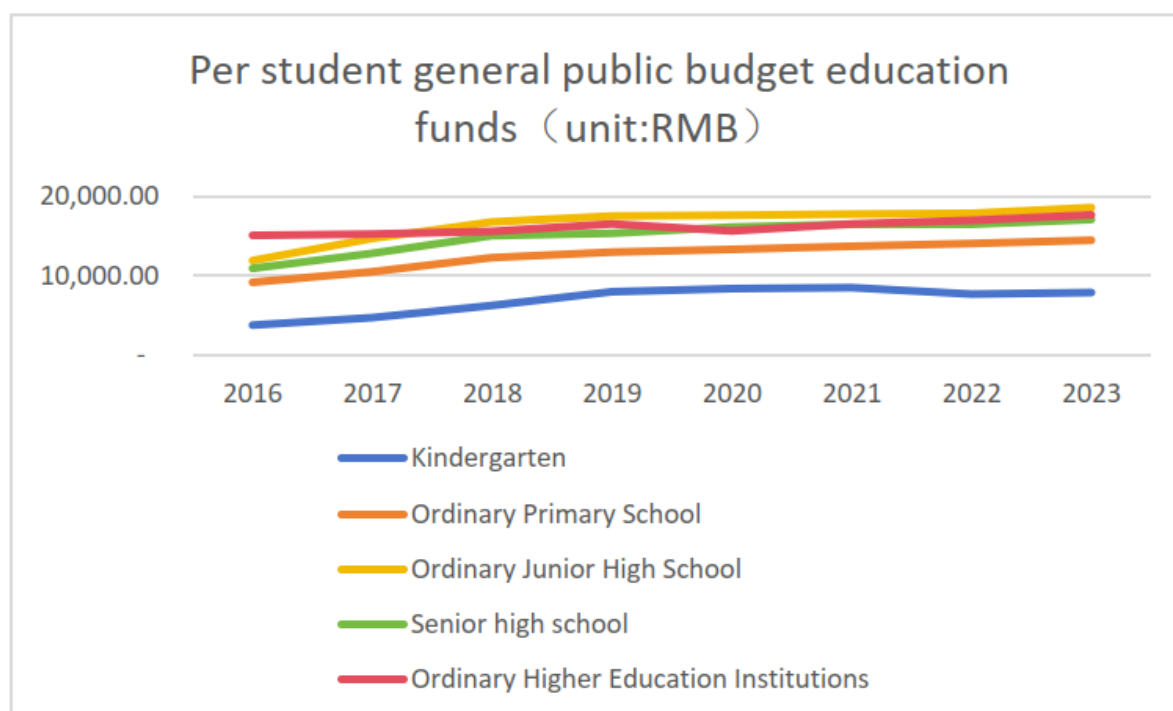
The investment structure of education at all levels (including the proportion of fiscal investment in preschool education, compulsory education, senior high school education, higher education, and vocational education).

Total investment of the general public budget for education funds (counted by kindergartens, regular primary schools, regular junior high schools, general senior high schools, and regular universities, 2016–2023):



The total investment of the general public budget for education funds has been in a state of growth in regular primary schools, general senior high schools, and regular universities, and the total investment in regular junior high schools and kindergartens has shown a state of growth and stability.

The per capita general public budget for education funds (counted by kindergartens, regular primary schools, regular junior high schools, general senior high schools, and regular universities, 2016–2023):



From the data, the per capita budget in the regular junior high school stage has always been the highest in Chongqing's public education budget, followed by the regular university stage, and the kindergarten stage is the lowest.

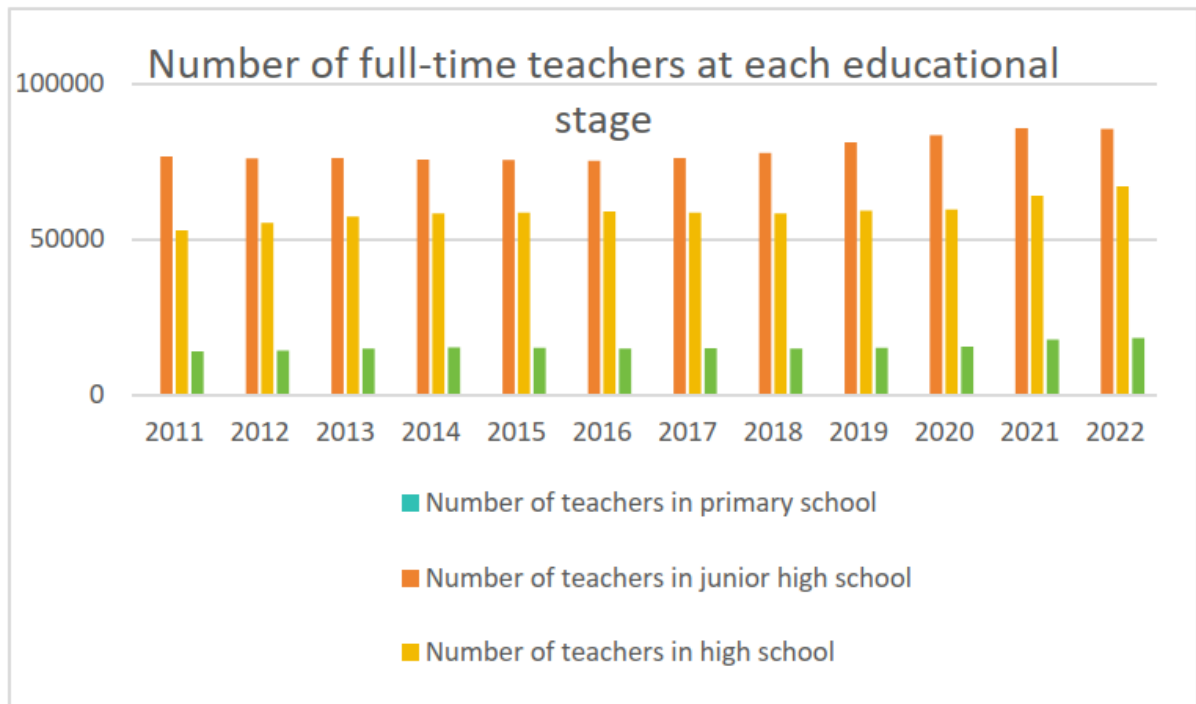
4.1.3 Development Characteristics of Educational Investment in Chongqing

From the aforementioned data, the total amount of educational investment in Chongqing has steadily increased, but its proportion is relatively low, and there is a prominent structural imbalance (with the proportion of investment in compulsory education being relatively high, while the investment in higher education is insufficient).

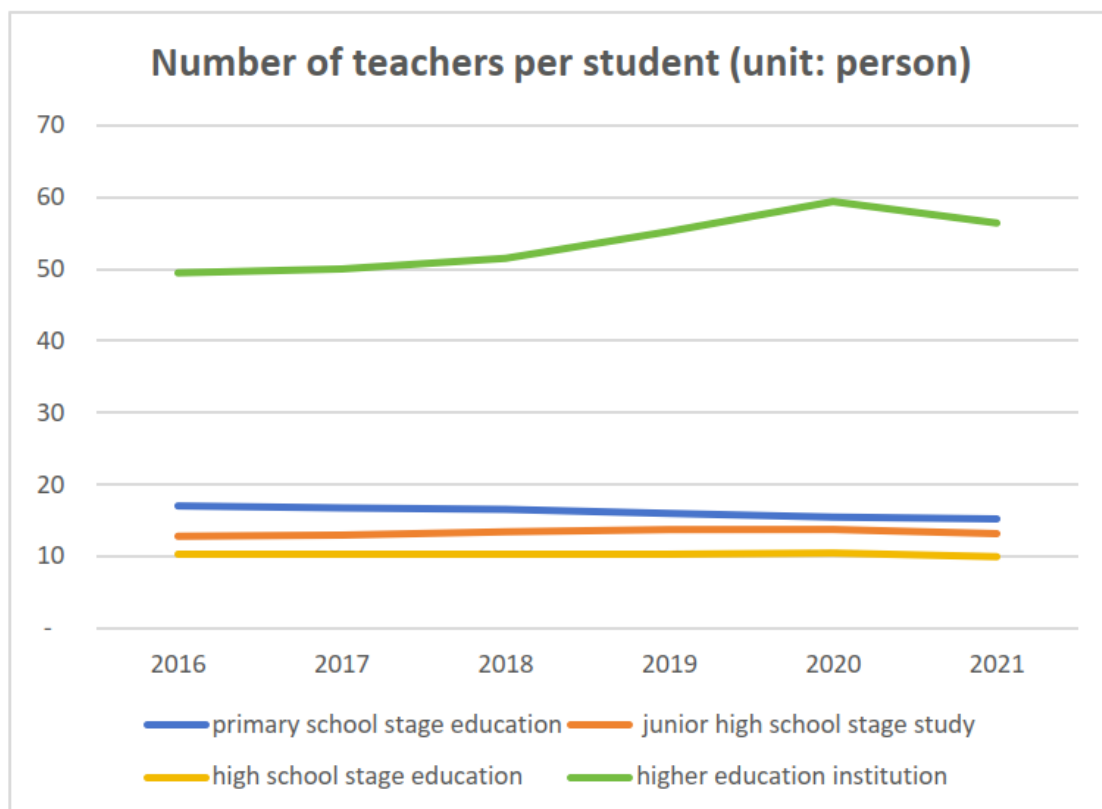
4.2 Current Situation and Characteristics of Educational Level in Chongqing

4.2.1 Evaluation Dimensions of Educational Level: Teachers' Strength (Number of Full-time Teachers, Student-Teacher Ratio)

Number of full-time teachers at all stages:

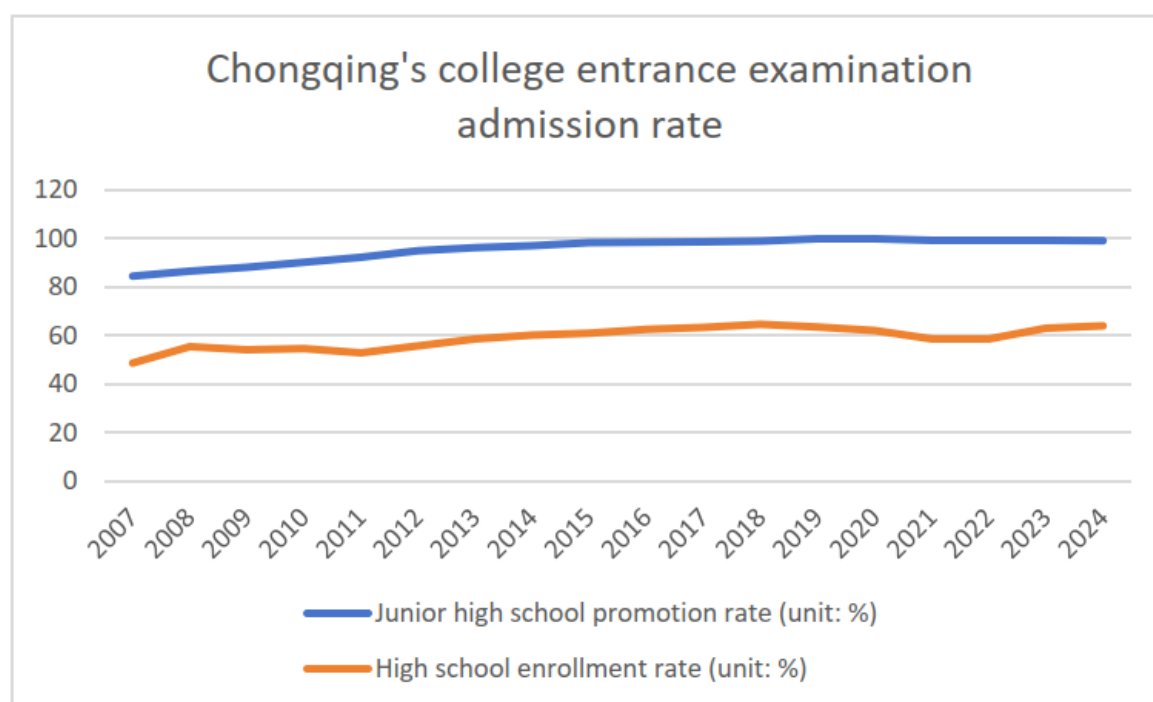


Number of teachers per student:



From the data on the per capita number of teachers, from 2016 to 2021, the student-teacher ratio in compulsory education and senior high school education has been relatively stable, while the student-to-teacher ratio in higher education has shown a trend of increasing and then rapidly decreasing.

Educational output (measured by the enrollment rate):



4.2.2 Time Change Trends of Educational Level in Various Dimensions

In terms of quantity, the ratio between the number of teachers and the number of students in compulsory education and senior high school education is relatively fixed, and the growth rate of the number of teachers in colleges and universities is lower than that of the number of students; in terms of enrollment rate, the junior high school enrollment rate has maintained an annual increase, while the senior high school enrollment rate has remained around 60% after rising to more than 50% in 2008, and has not shown an annual increase despite the year-by-year increase in the per capita budget for education funds.

4.3 Preliminary Judgment on the Realistic Correlation between Educational Investment and Educational Level Development in Chongqing

Based on the data on the senior high school enrollment rate and the per capita budget for education funds in Chongqing, there is no synchronous growth over time. Based on this, it is necessary to verify whether there are regional differences from the regional perspective. The relationship between educational investment data and enrollment rate in Yuzhong District (a typical urban area) and Chengkou County (a typical rural area) is analyzed.

Through public data retrieval, the educational fiscal expenditure data of Yuzhong District and Chengkou County from 2021 to 2023 are obtained as follows:

Annual	2021	2022	2023
Number of ordinary high school students enrolled in Yuzhong District	10960	10757	10959
Number of full-time teachers in regular senior high schools in Yuzhong District	1293	1341	1161
Investment in education funds in Yuzhong District (100 million yuan)	14.52	15.25	16.55

Per capita expenditure on education operating expenses from general public budgets for regular senior high schools (yuan)	31,321.14	31,509.07	36,180.05
Growth rate	0.02%	0.60%	14.82%
Per capita expenditure on public funds from general public budgets for regular senior high schools (yuan)	28,245.74	29,777.82	33,918.13
Growth rate	2.70%	5.42%	13.90%
Number of enrolled regular senior high school students in Chengkou County	5401	5262	5433
Number of full-time teachers in regular senior high schools in Chengkou County	1285	1282	1420
Investment in education funds in Chengkou County (100 million yuan)	6.21	6.4	6.4
Per capita expenditure on education operating expenses from general public budgets for regular senior high schools (yuan)	12,488.80	12,556.24	14,814.20
Growth rate	1.99%	0.54%	17.98%
Per capita expenditure on public funds from general public budgets for regular senior high schools (yuan)	11,269.73	11,847.69	11,998.00
Growth rate	7.36%	5.13%	1.27%

From the above table, the number of students in general senior high schools in Yuzhong District from 2021 to 2023 is about twice that of Chengkou County, but the overall educational fund investment in Yuzhong District is about 2.5 times that of Chengkou County. In terms of details, in terms of ensuring per capita educational expenditure investment, the per capita general public budget for education operating expenses in Yuzhong District is also almost 2.5 times that of Chengkou County. In terms of ensuring the operation of schools and reflecting the financial support capacity for daily teaching activities of schools, the per capita general public budget for public welfare funds in Yuzhong District is also almost 2.5 times that of Chengkou County. Although, according to Chongqing's educational policies, the growth rate of the above-mentioned expenditure in Chengkou County is faster than that in Yuzhong District, due to factors such as the base, Chengkou County still has a long way to go to catch up with Yuzhong District in educational investment.

In terms of teaching quality, the college entrance examination enrollment rate and student-teacher ratio data of Yuzhong District and Chengkou County are compiled according to public data. In terms of enrollment rate, according to public data, the undergraduate admission rate of senior high schools in Yuzhong District has long been among the top in the city, with 94% in 2023 and 95% in 2024; the public data of Chengkou County from 2023 to 2024 shows that the number of college entrance examination candidates admitted is 910 and 1054 respectively, with the ratios of 51.87% and 58.2% respectively. In terms of undergraduate admission rate, Yuzhong District has an absolute advantage over Chengkou County.

In terms of the ratio of students to teachers, Yuzhong District is about 8.65:1, with a further upward trend in recent years; Chengkou County is about 4:1, with a further downward trend in recent years. In terms of the ratio of the number of students to full-time teachers, although the ratio in Chengkou County is better than that in Yuzhong District, from the perspective of result indicators such as enrollment rate, the high teacher ratio in Chengkou County has not significantly improved the enrollment rate.

5. Analysis of the Problems and Causes in the Linkage Development of Educational Investment and Educational Level in Chongqing

5.1 Core Problems in the Linkage Development of Educational Investment and Educational Level in Chongqing

- i. The overall linkage and coordination between the two are relatively low, and the foundation for their coordinated development is weak (Xie, 2019).
- ii. The structural imbalance in educational investment restricts the effective realization of the linkage effect (excessive investment in compulsory education, insufficient investment in vocational education and higher education; large gaps in regional investment) (Jiang, 2016; Fan, 2014).
- iii. The efficiency of educational investment is low, and the driving effect of investment on educational development is weakened (low efficiency in the use of fiscal funds, underdeveloped channels for social investment) (Ding, 2018).

- iv. Significant regional differentiation in educational levels conversely restricts the overall linkage efficiency of investment (low educational levels in underdeveloped regions lead to low marginal benefits of investment) (Wang, 2011).
- v. A sound linkage mechanism between the two is absent, lacking a dynamic matching and feedback mechanism between investment and educational levels (Yuan, 2018; Xie, 2019)
- vi. The linkage between investment in vocational education and its development level is insufficient, which is inconsistent with the industrial development needs of Chongqing (in line with the development background of Chongqing's manufacturing and modern service industries) (Kang, 2021).

5.2 Analysis of the Causes of the Problems in the Linkage Development of Educational Investment and Educational Level in Chongqing

- i. Institutional Dimension: Under fiscal decentralization, local governments lack sufficient incentives for educational investment; the performance appraisal and supervision mechanisms for public educational funding are inadequate (Chu, 2017).
- ii. Economic Dimension: Significant disparities exist in regional economic development in Chongqing (economic gaps between the main urban area and southeast/northeast Chongqing), resulting in the regional imbalance of educational resource allocation (Zhang, 2021).
- iii. Structural Dimension: Educational investment is characterized by a bias toward quantity over quality and basic education over vocational/higher education; insufficient investment in the development of teaching staff has become a bottleneck that restricts the linkage (Qin, 2020).
- iv. Mechanism Dimension: There is a lack of dynamic monitoring, early warning, and feedback mechanisms between educational investment and educational levels; the diversified educational investment system remains incomplete, with low participation from social forces (Ding, 2018).
- v. Regional Coordination Dimension: Educational coordinated development within the Chengdu-Chongqing Economic Circle is insufficient, and cross-regional mechanisms for educational resource sharing and investment linkage have not been established.

6. Countermeasure Suggestions for Promoting the Positive Linkage between Educational Input and Educational Level in Chongqing

6.1. Optimize the Educational Input System and Lay a Solid Material Foundation for Their Linkage

6.1.1 *Expand the Scale of Fiscal Educational Input*

Municipal financial departments shall incorporate educational input into the medium- and long-term fiscal plan and establish a rigid growth mechanism. It is clarified that the proportion of fiscal educational input in GDP will increase by 0.2–0.3 percentage points annually from 2024 to 2028, striving to reach more than 4%, a national advanced level, by the end of 2028. Simultaneously, the proportion of educational input in local general public budget expenditure will be raised to 20%, ensuring the stability of input through the hard constraint of budget formulation (Huang, 2014). Construct an input monitoring system featuring "municipal overall planning and district/county implementation." A special working group jointly established by the Municipal Finance Bureau and the Municipal Education Commission will conduct quarterly inspections on the implementation of input and urge district/county finances to fully allocate educational funds through data disclosure, interviews, and supervision (Chu, 2017). Incorporate the compliance rate of educational input growth into the performance appraisal system of district/county governments with a weight of no less than 15%. For districts/counties that fail to meet the standards for two consecutive quarters, the amount of municipal special transfer payments for education will be reduced (Zhang, 2021).

District/county financial departments shall strictly follow the supporting requirement of "not lower than the municipal proportion," separately list educational input items in the annual budget, and ensure the full allocation of funds for key areas such as compulsory education and vocational education (Chen & Liu, 2018). Establish a linked accounting mechanism between educational input growth and the growth of fiscal recurrent revenue. When the year-on-year growth of fiscal recurrent revenue exceeds 5%, the year-on-year growth of educational input shall not be less than 8%, to ensure that input growth is compatible with the economic development level (Fan, 2014).

6.1.2 *Optimize the Structure of Educational Input*

Coordinate educational input at all levels: The Municipal Education Commission shall take the lead in formulating the "Implementation Rules for Optimizing the Structure of Educational Input in Chongqing (2024–2027)," clarifying the adjustment goals of the proportion of educational input at all levels. The proportion of fiscal input in vocational education will be increased from the current 12% to 18% by 2027, the proportion of input in higher education from 20% to 25%, and the proportion of input in compulsory education will be maintained at around 50%, with a focus on tilting towards rural compulsory education. Among them, the funds used for improving school-running conditions shall account for no less than 40% of the total input in compulsory education (Kang, 2021). Establish a special municipal development fund for vocational education, which will be jointly supervised by the Municipal Finance Bureau, the Municipal Education Commission, and the Municipal Bureau of Human Resources and Social Security, with an annual budget scale of no less than 1.5 billion yuan. It will focus on supporting key areas such as the standardized construction of training bases in vocational colleges, the

approval of industry-education integration projects, and the training of "double-qualified" teachers (Ma, 2017).

Coordinate regional educational input: Municipal financial departments shall increase the intensity of educational transfer payments to the southeast and northeast regions of Chongqing. The transfer payment funds will grow at an annual rate of more than 10%, of which 80% will be designated for improving the school-running conditions of rural schools, supplementing teachers, and updating equipment (Zhao, 2012). Establish an educational pairing assistance fund mechanism of "main urban area – northeast Chongqing – southeast Chongqing," requiring 9 main urban districts such as Yuzhong District and Jiangbei District to allocate 3% of their district-level educational fiscal budget as assistance funds every year, which will be specially used for school building maintenance, teaching equipment purchase, and teacher training in counterpart districts and counties (Zhang, 2021). The Municipal Education Commission shall construct an evaluation system for the regional educational input balance index, conduct annual evaluations based on 6 core indicators such as per capita educational funds and the compliance rate of teacher allocation. For districts and counties with a declining balance index, the approval of municipal educational infrastructure projects will be suspended until rectification is completed (Chen & Liu, 2018).

6.1.3 Improve the Efficiency of Educational Input

The Municipal Finance Bureau and the Municipal Education Commission shall jointly issue the "Measures for the Performance Appraisal and Management of Educational Fiscal Funds in Chongqing," constructing a quantitative evaluation system consisting of 12 indicators such as the timeliness rate of fund allocation, the input-output ratio per student, and the equipment utilization rate. The assessment results will be directly linked to fund allocation in the next year, and districts and counties with excellent assessments will be awarded an additional 5% of municipal special educational funds (Wang, 2010). Establish a full-life-cycle supervision mechanism for educational funds. The Municipal Audit Bureau will conduct a special audit of educational funds every two years, focusing on investigating and verifying issues such as fund misappropriation, idleness, and inefficient use. The audit results will be reported to the Standing Committee of the Municipal People's Congress, and units and individuals who improperly use funds will be held accountable in accordance with laws and regulations (Ding, 2018).

The Municipal Education Commission shall build a service platform for social educational input and improve the mechanism of "donation incentives + information disclosure + process supervision" (Ding, 2018). For enterprises with an annual donation of more than 10 million yuan, the enterprise income tax pre-tax deduction policy shall be implemented in accordance with relevant regulations, and they will be awarded the title of "Outstanding Contribution Unit to Educational Public Welfare" by the municipal government. For private schools, a per-student public operating fund subsidy will be given based on the number of students enrolled, with the subsidy standard not lower than 80% of that of public schools at the same level, and the subsidy funds will be directly allocated to the special accounts of the schools (Huang, 2014). Establish a social input information disclosure system and regularly disclose details of the use of donated funds and project implementation effects through the municipal educational government affairs website to accept social supervision (Chu, 2017).

6.2 Take Multiple Measures to Improve Educational Level and Strengthen the Feedback Effect on Educational Input

6.2.1 *Promote the High-quality and Balanced Development of Education*

The Municipal Education Commission shall issue the "Action Plan for the High-quality and Balanced Development of Urban-Rural Education in Chongqing (2024–2028)," clarifying the goal of achieving full coverage of high-quality and balanced development of compulsory education at the county level by 2026 (Ma, 2017). Implement the "Rural School Quality Improvement Project." Led by district/county educational departments, through methods such as "staffing sinking and special recruitment," each rural complete primary school will be equipped with at least 3 full-time teachers for music, physical education, and art by 2025, and the teacher staffing will be comprehensively guaranteed by the municipal finance (Qin, 2020). Establish a rigid mechanism for the rotation and exchange of principals and teachers between urban and rural schools. It is required that principals and backbone teachers with intermediate or above professional titles in urban public schools must have at least 1 year of working experience in rural schools every 5 years. During the rotation period, their salary and benefits will be increased by 20%, and the work experience will be a necessary condition for professional title promotion and selection of excellent personnel (Du, 2015).

Promote the digital transformation of education. The Municipal Education Commission and the Municipal Finance Bureau shall jointly approve the "Rural Education Informatization Upgrade Project" with a total investment of 2 billion yuan. By 2025, full coverage of gigabit networks and 100% equipping of multimedia classrooms in rural schools will be realized (Kang, 2021). Construct a municipal sharing platform for high-quality educational resources, integrating high-quality courseware and live courses from key schools in the main urban area. Rural schools are required to offer no less than 4 shared courses every week. District/county educational departments will conduct effectiveness evaluations through classroom inspections and student questionnaires, and the evaluation results will be incorporated into the annual assessment of the schools (Sun, 2016).

6.2.2 *Strengthen the Construction of Teachers' Teams*

The Municipal Education Commission shall implement the "Chongqing Famous Teacher Training Project," establishing a full-chain mechanism of "selection – training – assessment – radiation." Every year, 100 backbone teachers will be selected to participate in national-level training, and 200 teachers will be sent to work and study in developed areas in the east. The training funds will be fully guaranteed by the municipal finance (Qin, 2020). Improve the teacher salary guarantee system. District/county financial departments shall strictly implement the provision that "the average salary level of teachers shall not be lower than the average salary level of local civil servants" and issue township work subsidies to rural teachers, which are divided into 3 grades according to the remoteness of the townships. The subsidy standards are 500 yuan, 800 yuan, and 1200 yuan per month, respectively, which are fully allocated into the fiscal budget (Du, 2015).

Optimize the teacher recruitment and allocation mechanism. The Municipal Bureau of Human Resources and Social Security and the Municipal Education Commission shall jointly issue special recruitment policies for teachers in rural schools. For full-time undergraduates and

above who teach in rural schools in southeast and northeast Chongqing, a one-time settlement allowance of 30,000–50,000 yuan will be given, and their staffing issues will be prioritized (Qin, 2020). Establish a teacher withdrawal mechanism. Teachers who fail the performance assessment for two consecutive years and are not suitable for teaching positions will be regulated to transfer or dismissal, to ensure the overall quality of the teachers' team (Chen & Liu, 2018).

6.2.3 Improve Educational Quality

The Municipal Education Commission shall take the lead in revising the "Chongqing Educational Quality Evaluation System," constructing a diversified evaluation framework of "moral education + comprehensive quality." For compulsory education, the weight of academic performance in further education will be weakened, and evaluation indicators such as students' physical health, artistic literacy, and practical ability will be added, accounting for no less than 40%. For senior high school education, the assessment of innovative practice, career planning, and other dimensions will be strengthened. For higher education, core indicators such as talent training quality, scientific research achievement transformation, and social service contribution will be highlighted (Liu, 2013). Establish a public disclosure system for educational quality evaluation results and release the quality evaluation reports of districts, counties, and schools to the public through official channels every year to accept public supervision (Xie, 2019).

Deepen the integration of vocational education with industry. The Municipal Education Commission, the Municipal Development and Reform Commission, and the Municipal Economic and Information Commission shall jointly formulate the "Measures for Promoting the Integration of Vocational Education with Industry in Chongqing," requiring each vocational college to establish in-depth cooperative relations with at least 3 key regional industrial enterprises to jointly build industrial colleges and training bases and develop curriculum standards (Ding, 2018). Implement preferential tax policies for enterprises participating in vocational education. Enterprise donations for vocational education through public welfare social organizations or people's governments at or above the county level and their departments shall be deducted when calculating the taxable income within 12% of the annual total profit; the excess part may be carried forward and deducted in the next 3 years when calculating the taxable income (Kang, 2021). Promote the "order-based training" model. Centering on the needs of Chongqing's pillar industries such as electronic information, automobile manufacturing, and modern logistics, enterprises and schools will jointly formulate talent training plans. The employment rate of students will be incorporated into the core performance appraisal indicators of vocational colleges, and majors with an employment rate lower than 85% will be suspended from enrollment (Ding, 2018).

6.2.4 Accumulate Human Capital Stock

The Municipal Education Commission and the Municipal Bureau of Human Resources and Social Security shall jointly build the "Chongqing Platform for Linking Educational Output with Industrial Demand," holding no less than 10 enterprise-school talent matching meetings every year. Establish an incentive mechanism for graduates to find employment locally. For enterprises that recruit graduates from Chongqing's colleges, universities, and vocational colleges and sign labor contracts of more than 1 year, a social security subsidy of 1,000 yuan

per person will be given (Fan, 2014). Improve the mechanism for transforming educational achievements, encouraging colleges and universities, vocational colleges, and enterprises to jointly build scientific research and innovation platforms. No less than 60% of the income from the transformation of scientific research achievements will be distributed to the research team, and the remaining part will be used for the construction of scientific research platforms and talent training (Sun, 2016).

Construct a lifelong education system. District/county educational departments shall take the lead in building community education colleges, integrating teachers' resources from vocational colleges and universities, and offering courses such as vocational skill improvement and cultural literacy training. The annual fiscal input shall not be less than 5 million yuan, which will be used for teacher recruitment, venue renovation, and teaching equipment updates (Qin, 2020). Establish a lifelong learning credit bank to realize the mutual recognition and conversion of learning achievements at different educational stages and of different types, to promote the continuous accumulation of human capital (Fan, 2014).

6.3 Construct a Positive Linkage Mechanism between Educational Input and Educational Level to Ensure Coordinated Development

6.3.1 Establish a Dynamic Monitoring and Matching Mechanism

The Municipal Education Commission and the Municipal Bureau of Statistics shall jointly establish the "Chongqing Monitoring Center for the Linkage between Educational Input and Educational Level", and construct a monitoring system consisting of 6 categories and 30 indicators, including input scale, structure, efficiency, educational quality, teachers' level, and output benefits, so as to realize real-time data collection and dynamic updates (Xie, 2019). A research and judgment team composed of experts in fields such as educational economics and statistics shall be set up to conduct in-depth data analysis every six months, form the "Research and Judgment Report on Linkage Development", and put forward targeted suggestions for adjusting the input structure and optimizing resource allocation to provide a basis for municipal decision-making (Wang, 2011).

Formulate differentiated input standards based on monitoring data. For core urban areas, focus on increasing input in higher education and vocational education, with an emphasis on scientific research platform construction and industry-education integration projects. For rural areas, focus on ensuring input in compulsory education, giving priority to meeting the standards of school-running conditions and supplementing teachers. For pre-school education, implement a two-track guarantee of "per-student funds + public operating funds" according to the permanent population scale, so as to ensure that the input accurately aligns with the needs of educational development (Yuan, 2018).

6.3.2 Establish a Feedback and Incentive Mechanism

The Municipal Finance Bureau and the Municipal Education Commission shall jointly formulate the "Measures for the Performance Appraisal of Educational Input in Chongqing", incorporating the effectiveness of educational level improvement into the core assessment dimensions, including 8 quantitative indicators, such as the consolidation rate of compulsory education, the gross enrollment rate of senior high school education, the undergraduate

admission rate, and the employment rate of graduates from vocational colleges (Chu, 2017). The assessment results are divided into four grades: excellent, good, qualified, and unqualified. For districts and counties with excellent assessments, a reward fund of 5% of the total annual educational input shall be provided, which can be used for key educational projects as a whole. For districts and counties with unqualified assessments, the amount of municipal educational transfer payments in the next year will be reduced, and special supervision and rectification will be carried out by municipal departments (Zhang, 2021).

Establish a feedback and incentive mechanism at the school level, incorporating indicators such as the improvement of students' comprehensive quality, the effectiveness of teachers' team construction, and social satisfaction into the school's performance appraisal. Schools with excellent assessments may draw 10% of the total annual public operating funds as reward funds, which will be used for teachers' performance payment and teaching condition improvement, so as to fully stimulate the endogenous motivation of the schools (Xie, 2019).

6.3.3 Establish a Regional Linkage Mechanism

The Municipal Education Commission shall take the lead in establishing the "Education Linkage Development Alliance of Main Urban Area - Northeast Chongqing Southeast Chongqing", adopting a "1+N" pairing model (1 main urban area paired with 2-3 remote districts and counties), and establishing a normalized mechanism for resource sharing, teacher exchange, and joint teaching research (Zhang, 2021). Formulate the "Evaluation Index System for Regional Educational Linkage Development", and conduct annual assessments based on aspects such as the arrival rate of assistance funds, the number of teacher exchanges, and the improvement range of teaching quality. The assessment results shall be linked to the performance appraisal of the governments of both parties (Zhao, 2012).

Build a cross-regional sharing platform for educational resources, integrating elements such as high-quality curriculum resources, teaching and scientific research achievements, and training bases from various districts and counties, establishing a resource sharing list, and implementing a mechanism of "application on demand and free use" (Yuan, 2018). Promote the group-based school-running model of key schools in the main urban area, encouraging schools of the same level, such as Bashu Middle School and Chongqing No.1 Middle School, to drive the improvement of the management level and teaching quality of schools in remote districts and counties through trusteeship and cooperative school-running. For cooperative projects with remarkable results, municipal special educational funds shall be provided as support (Ma, 2017).

6.4 Expand the External Space for Linkage Development in Combination with the Construction of the Chengdu-Chongqing Twin-City Economic Circle

6.4.1 Promote the Coordination of Educational Input between Sichuan and Chongqing

The Municipal Finance Bureau and the Municipal Education Commission shall jointly establish a coordination mechanism for educational fiscal input between Sichuan and Chongqing with the Sichuan Provincial Department of Finance and the Department of Education, holding an annual joint meeting on coordinated development to share core information such as educational input policies, budget formulation experience, and fund management models (Zhang, 2021). Establish a special fund for the coordinated development of education between

Sichuan and Chongqing, with funds contributed by the finance of both places in a ratio of 1:1, and an annual budget scale of no less than 2 billion yuan, focusing on supporting cross-regional educational cooperation projects, the construction of major scientific research platforms, and the sharing of high-quality resources (Li & Zhang, 2015).

Construct an information-sharing platform for educational input between Sichuan and Chongqing, unifying the statistical caliber of input, and regularly release input data of both places to provide data support for the optimal allocation of regional educational resources (Wang, 2011). Explore the establishment of a cross-regional transfer payment mechanism for educational input, providing fund subsidies for schools that run schools across regions and cooperate in cultivating talents in the twin-city economic circle, so as to promote the balanced allocation of resources (Chen & Liu, 2018).

6.4.2 Promote the Coordinated Improvement of Educational Level between Sichuan and Chongqing

Educational departments of Sichuan and Chongqing shall jointly formulate the "Action Plan for the Coordinated Development of Education in the Chengdu-Chongqing Twin-City Economic Circle", and carry out joint teacher training across regions, hold joint training courses for backbone teachers and principal forums every year, with a training scale of no less than 1,000 person-times (Zhang, 2021). Establish a mutual recognition mechanism for educational quality evaluation between Sichuan and Chongqing, unify core evaluation indicators, and mutually recognize teaching achievements and credits of schools in each other's regions to promote the coordination of educational quality standards (Xie, 2019).

Jointly promote the integration of vocational education with industry. Human resources and social security, education, and economic and information departments of Sichuan and Chongqing shall jointly identify regional industrial needs, co-construct vocational education professional catalogues and curriculum standards, and share training base resources. Encourage vocational colleges in Sichuan and Chongqing to cooperate with cross-regional enterprises in joint enrollment and joint training, so as to promote the free flow of talents in the twin-city economic circle and improve the adaptability of talent training to industrial needs (Kang, 2021).

6.4.3 Realize the Three-Dimensional Linkage of Educational Input - Educational Level - Industrial Development

The Municipal Education Commission, the Municipal Development and Reform Commission, and the Municipal Economic and Information Commission shall jointly optimize the input structure of vocational education and higher education around the key industries of the Chengdu-Chongqing Twin-City Economic Circle, focusing on increasing input in majors such as electronic information, automobile manufacturing, and modern logistics (Ding, 2018). Establish a docking mechanism between industrial demand and educational input, conduct an annual survey on the demand for industrial talents, and adjust the professional settings and input directions according to the survey results to ensure that the educational input aligns with industrial development (Sun, 2016).

Promote the establishment of industry-university-research cooperation alliances between colleges and universities, vocational colleges, and key enterprises in the region of Sichuan

and Chongqing, jointly carrying out technological research and development and talent training. Enterprises' investment in cooperation may enjoy preferential tax policies in accordance with relevant regulations (Kang, 2021). Establish a coordination mechanism between the improvement of educational level and industrial development, incorporating talent training quality, graduate employment rate, and industrial fit into the core indicators of educational assessment, so as to promote the positive interaction between educational input, educational level, and industrial development, and form a closed-loop system of "input supporting education, education serving industry, and industry feeding back input" (Xie, 2019).

6.5 Strengthen Policy Guarantee to Provide Institutional Support for Their Positive Linkage

6.5.1 Improve Local Educational Fiscal Laws and Regulations

The Standing Committee of the Municipal People's Congress shall accelerate the formulation of the "Regulations of Chongqing on the Guarantee of Educational Fiscal Input", clarifying the core contents such as the growth mechanism, structure requirements, and responsible subjects of educational input, and incorporating the guarantee of educational input into the track of legalization (Huang, 2014). The regulations shall clearly stipulate that the annual growth rate of educational input of municipal and district/county finances shall not be lower than the growth rate of fiscal recurrent revenue, so as to ensure the stable growth of input. Clarify the division of responsibilities of governments at all levels in educational input to avoid shirking of responsibilities (Chu, 2017).

Establish a supervision mechanism for the implementation of laws and regulations. The Standing Committee of the Municipal People's Congress will conduct a law-enforcement inspection on the implementation of the regulations every two years, and hold districts and counties governments accountable for violating the regulations to ensure the implementation of the regulations and to provide legal guarantee for the linkage development between educational input and educational level (Xie, 2019).

6.5.2 Increase Policy Support

The Municipal Education Commission and the Municipal Finance Bureau shall jointly issue the "Several Policies of Chongqing on Promoting the Linkage Development between Educational Input and Educational Level", formulating special support policies for key areas such as remote districts and counties, weak schools, and vocational education (Li & Zhang, 2015). Give priority to guaranteeing educational land for districts and counties in southeast and northeast Chongqing, and the supply of educational land shall account for no less than 15% of the total annual construction land supply. Provide tax preferences for rural schools and private schools, exempting them from real estate tax and urban land use tax for self-used real estate and land (Zhao, 2012).

Establish a tracking mechanism for policy implementation. The Municipal Education Commission and the Municipal Finance Bureau shall jointly inspect the implementation of policies every quarter, and timely discover and solve problems in the process of policy implementation through on-site investigations and discussions, so as to ensure the full release of various policy dividends (Yuan, 2018).

6.5.3 Strengthen Educational Supervision

The Municipal People's Government Education Supervision Commission shall incorporate the coordination level of the linkage between educational input and educational level into the core content of comprehensive educational supervision, conduct a special supervision every year, and release the supervision results to the public, which shall be used as an important basis for the assessment and selection of excellent leading bodies of district and county governments (Qin, 2020). The supervision content covers multiple dimensions such as input growth, structure optimization, fund efficiency, educational quality improvement, and regional balance, so as to ensure the comprehensiveness and relevance of the supervision (Chen & Liu, 2018).

Establish a supervision and rectification mechanism. For problems found in the supervision, issue rectification notices to relevant districts, counties, and departments, clarifying the rectification time limit and requirements, which shall be followed up and supervised by the supervision commission (Chu, 2017). Introduce third-party evaluation institutions to conduct independent evaluations on the effectiveness of linkage development. The evaluation results shall be used as an important reference for supervision and rectification and policy adjustment, so as to promote the continuous optimization of the linkage development between educational input and educational level (Xie, 2019).

7. Research Conclusions and Future Prospects

7.1 Main Research Conclusions

Firstly, the guarantee of educational fiscal expenditure is insufficient, and the problem of structural imbalance is prominent, with significant investment gaps between urban and rural areas and different regions (Fan, 2014). Although the total amount of fiscal educational expenditure in Chongqing has continued to grow, its proportion of GDP and of local general public budget expenditure has been relatively low for a long time, and the fund guarantee does not match the demand for high-quality educational development; in terms of investment structure, the proportion of investment in compulsory education is relatively high, while the investment in vocational education and higher education is relatively insufficient, and there is a huge gap in the total funds and per capita expenditure between urban areas represented by Yuzhong District and rural areas represented by Chengkou County. Due to the disadvantage of the base, it is difficult for rural areas to bridge the investment gap with urban areas in the short term. At the same time, some regions have the phenomenon of "emphasizing investment over output", and the efficiency of fund use and transformation needs to be improved (Chu, 2017).

Secondly, the educational level shows regional differentiation characteristics, and there are structural contradictions in the dimensions of teachers and output. The allocation of teachers in compulsory education and senior high school education has tended to be reasonable on the whole, but the pressure of teacher guarantee in higher education is relatively large; the teachers in urban and rural areas show differentiated characteristics, with "rural areas being superior in quantity ratio, while urban areas are leading in quality and literacy". In terms of educational output, the junior high school enrollment rate has been close to saturation, while

the senior high school enrollment rate has fluctuated for a long time and has not formed a synchronous linkage with the growth of educational fiscal expenditure, reflecting the obstruction in the transmission mechanism of converting investment into output. In addition, there is a huge gap between urban and rural areas such as Yuzhong District and Chengkou County in core output indicators such as teaching quality and undergraduate admission rate, and the problem of regional differentiation of educational level is prominent (Ma, 2017).

Thirdly, the coordination degree of the linkage between educational fiscal expenditure and teaching quality is relatively low, with obvious heterogeneity characteristics and transmission obstacles. The two have not formed a benign collaborative pattern of "investment driving level improvement and level feedback optimizing investment", and the overall linkage efficiency is insufficient; among different types of expenditure, the driving effect of hardware investment and teacher investment is more significant, and between urban and rural areas, there are heterogeneous characteristics of "higher linkage efficiency in urban areas and lower marginal benefit of investment in rural areas". The insufficient investment in teacher team construction, unbalanced investment structure, and uneven regional resource allocation are the core crux leading to the obstruction of the transmission path between the two (Fan, 2014).

Fourthly, the core problems and multi-dimensional causes of linkage development are clear, and the optimization countermeasures have clear targeting. At present, there are five core problems in the linkage development between the two in Chongqing: low linkage coordination degree, unbalanced investment structure, low investment efficiency, significant regional differentiation, and lack of a linkage mechanism. In addition, the linkage between vocational education investment and educational level is insufficient, and the adaptability to the needs of industrial development is poor. These problems are the result of the combined effect of multiple factors such as insufficient incentives for fiscal decentralization, regional economic differences, deviation of investment orientation, lag in mechanism construction, and insufficient regional coordination. The five core countermeasures proposed based on this, including "total guarantee, structural optimization, efficiency improvement, mechanism improvement, and regional coordination", can effectively solve the transmission obstruction, narrow the urban-rural and regional gaps, and improve the linkage coordination level between the two (Yuan, 2018; Chu, 2017).

Fifthly, the research results have regional adaptability and reference value. Focusing on the dual background of Chongqing's urban-rural dual structure and national strategic missions, the laws of linkage development, core problems, and optimization paths of educational investment and teaching quality extracted in this study not only provide a targeted reference for the construction of Chongqing as an educational powerhouse city and the balanced and high-quality development of urban-rural education, but also provide replicable and promotable practical experience for similar regions with urban-rural dual characteristics in the west (Huang, 2014).

7.2 Future Research Prospects

- i. Expanding Research Data: Incorporate panel data at the district and county level in Chongqing to further refine research on regional heterogeneity; extend the time span of data to analyze the long-term linkage effect.

- ii. Enriching Research Methods: Introduce spatial econometric models to analyze the spatial linkage effect between educational investment and educational levels in Chongqing; adopt policy shock models (e.g., the *Double Reduction* policy and the Chengdu-Chongqing Economic Circle policy) to examine their impacts on the linkage effect (Wang, 2011).
- iii. Deepening Research Content: Explore the precise linkage mechanisms between disaggregated indicators of educational investment (e.g., investment in teaching staff, investment in school-running conditions) and disaggregated dimensions of educational levels; investigate the linkage effect of digital educational investment against the backdrop of educational digital transformation (Sun, 2016).
- iv. Broadening Research Perspectives: Integrate the linkage effect between educational investment and educational levels with regional economic growth to explore the coupled and coordinated relationship among the three (Xie, 2019).

The data used in this paper are mainly from publicly released statistical bulletins, government documents, and relevant public data.

8. Data Sources

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Safe-Haven Attributes and Market Dynamics of Cryptocurrencies under Geopolitical Shocks: A Case Study of the Russia–Ukraine Conflict

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Abstract

Against the backdrop of the 2022 Russo-Ukrainian War, this paper examines the behavior of cryptocurrencies as alternative assets during periods of geopolitical crisis, with a focus on their safe-haven potential and market dynamics. We adopt a multi-stage event-driven framework to analyze the crypto market's response to escalating geopolitical tensions, comparing it to the performance of traditional safe-haven assets like gold and the U.S. dollar.

The study decomposes the Russo-Ukrainian conflict into distinct phases—initial escalation, prolonged confrontation, and tentative de-escalation—to assess crypto volatility, cross-asset correlations, and on-chain metrics. Our analysis reveals that cryptocurrencies exhibited heightened volatility during crisis peaks, with Bitcoin showing a transient negative correlation with traditional equity markets, but failing to maintain consistent safe-haven properties over the long term. Unlike gold, which demonstrated stable risk-mitigation capacity, crypto assets were dominated by speculative trading behavior, particularly in the early stages of the conflict.

We further find that on-chain activity, including transaction volumes and exchange outflows, was closely tied to geopolitical news flow, while some crypto assets displayed short-term hedging characteristics, their overall performance was constrained by liquidity shocks and regulatory uncertainty. This research contributes to the growing literature on crypto assets under extreme market stress, highlighting their limitations as reliable safe havens and providing insights for investors navigating geopolitical risk.

1. Definition of Core Concepts

Safe-haven assets retain or increase value during market turbulence, such as gold and U.S. Treasuries. This paper examines whether cryptocurrencies exhibit safe-haven properties during geopolitical crises, comparing their performance to traditional safe havens.

Cryptocurrency is a decentralized digital currency secured by cryptography, operating on blockchain technology to eliminate reliance on central authorities like banks. It enables peer-to-peer transactions with transparency and immutability, with Bitcoin as the first and most

prominent example. In this paper, it is the core asset class examined for its response to geopolitical risks and safe-haven properties.

Blockchain is a decentralized, immutable digital ledger that records cryptocurrency transactions across a network. It forms the technical foundation of cryptocurrencies, ensuring the transparency and security of on-chain metrics used in this study.

On-chain metrics are data points derived from blockchain transactions, including active addresses, transaction fees, and Total Value Locked (TVL). In this paper, they are used to analyze investor behavior and supply-demand dynamics in the crypto market during geopolitical events.

Hedging is a risk management strategy that uses assets or derivatives to offset potential losses from adverse price movements. This paper assesses whether cryptocurrencies can hedge against geopolitical risks by reducing portfolio volatility during crises.

2. Introduction

The outbreak of the Russo-Ukrainian War in February 2022 marked one of the most significant geopolitical shocks to the global financial system in recent decades. On 24 February 2022, Russia launched a full-scale military invasion of Ukraine, triggering a sharp escalation in geopolitical risk, economic sanctions, and global market uncertainty. Financial markets reacted immediately: global equity indices declined, energy and commodity prices surged, and investors shifted capital toward traditional safe-haven assets such as gold and U.S. Treasury securities.

During this period, cryptocurrencies—frequently described as “digital gold”—became a focal point of both public debate and academic inquiry. However, major cryptocurrencies exhibited pronounced price volatility in the immediate aftermath of the invasion, raising fundamental questions regarding their ability to function as safe-haven assets under extreme geopolitical stress. Specifically, this study asks: to what extent can major cryptocurrencies provide protection during wartime, and how do their behaviors differ from those of traditional safe-haven assets?

The roots of the conflict can be traced back to Russia’s annexation of Crimea in 2014, yet the 2022 escalation represented a structural break in global geopolitical risk. This break is clearly reflected in sharp increases in widely used risk indicators such as the Geopolitical Risk Index (GPR; Caldara & Iacoviello, 2022) and the CBOE Volatility Index (VIX; CBOE, 1993), both of which reached elevated levels following the invasion.

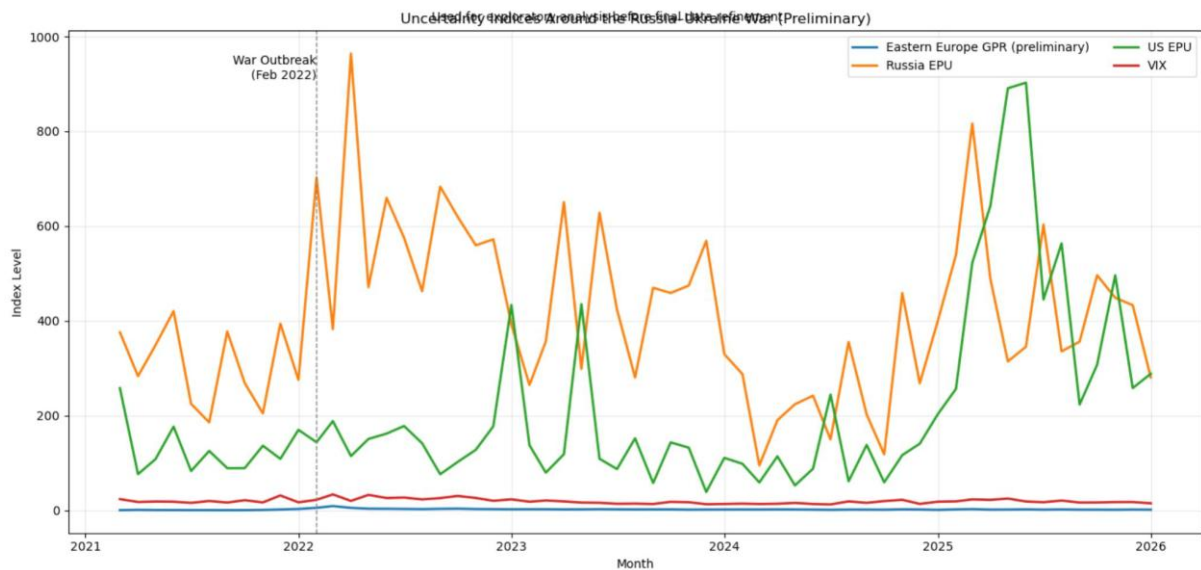


Figure 1: GPR, VIX Russia EPU and US EPU with war onset marked

Historically, prolonged geopolitical conflicts have reinforced the dominance of traditional safe-haven assets, while exposing vulnerabilities in speculative and high-volatility markets. Whether cryptocurrencies can challenge this historical pattern remains an open empirical question. While existing studies have examined cryptocurrency volatility and risk spillovers, three gaps persist: (i) insufficient focus on prolonged conflicts rather than short-lived shocks; (ii) limited differentiation among heterogeneous cryptocurrencies; and (iii) a lack of practical portfolio implications during wartime conditions.

Accordingly, this study investigates whether cryptocurrencies exhibited safe-haven characteristics during different phases of the Russo-Ukrainian War, how their market and on-chain indicators evolved alongside geopolitical risk, and what implications these dynamics hold for investor allocation strategies.

3. Literature Review

3.1 Evolution of Safe-Haven Asset Theory and Crypto Assets

3.1.1 Theoretical Foundations of Traditional Safe-Haven Assets

The core definition of a safe-haven asset was formally established by Baur and McDermott (2010): an asset that exhibits no correlation or negative correlation with stock returns during periods of significant equity market decline. Traditional safe-haven assets, such as gold, the U.S. dollar, the Swiss franc, and government bonds, have demonstrated the ability to maintain or increase their value during market turbulence, a property validated by extensive empirical research. For example, gold's safe-haven effect stems from its scarcity and its globally recognized store of value, while the U.S. dollar's safe-haven status relies on the stability of the U.S. economy and its role as the global reserve currency.

3.1.2 Controversies and Empirical Evidence on Crypto Assets' Safe-Haven Properties

Early studies were skeptical of crypto assets' safe-haven attributes. Dyhrberg (2015) conducted the first systematic comparison of Bitcoin and gold, finding that Bitcoin exhibited gold-like hedging properties under certain market conditions, though its significantly higher volatility undermined its reliability as a long-term safe haven. Bouri et al. (2016) further proposed stricter criteria for safe-haven assets, requiring three conditions: (1) no correlation with risky assets under normal market conditions; (2) negative correlation with risky assets during market downturns; and (3) stability during extreme market declines. Bitcoin was found to meet these criteria only partially in specific scenarios. Subsequent research has shown that Bitcoin may exhibit short-term safe-haven characteristics in local conflicts (Yermack, 2016) but may fail during global political crises. Additionally, Auer and Claessens (2020) noted that stricter national capital controls amplify the safe-haven effect of crypto assets, highlighting the context-dependent nature of their safe-haven properties.

3.2 Geopolitical Risk and Crypto Asset Response Mechanisms

3.2.1 Measuring Geopolitical Risk: The Construction of the GPR Index

Caldara and Iacoviello (2022) developed the Geopolitical Risk Index (GPR), which quantifies geopolitical risk by analyzing the frequency of keywords related to geopolitical tensions in major newspapers. This index has become a standard tool for studying the impact of geopolitical shocks on financial markets, though its application to crypto assets remains in its infancy.

3.2.2 Heterogeneous Responses of Crypto Assets to Geopolitical Risk

Existing research indicates that crypto assets respond asymmetrically to geopolitical risk. Bouri et al. (2016) found that Bitcoin performs well when the GPR index rises, particularly during political instability in developing countries, while other crypto assets like Ethereum are more susceptible to technical factors and exhibit weaker safe-haven properties (Liu & Tsyvinski, 2018). Furthermore, local conflicts and global crises exert distinct effects on crypto assets: in localized conflicts such as the Russo-Ukrainian War, cryptocurrencies may demonstrate short-term safe-haven effects, but in global political crises, their safe-haven function may be undermined by liquidity shocks and panic selling. This heterogeneity reflects the interplay between crypto assets' speculative and safe-haven attributes, underscoring the need for more granular scenario analysis in future research.

3.3 The Role of Crypto Assets in Portfolio Allocation

3.3.1 Extensions of Traditional Portfolio Theory

Markowitz's (1952) Modern Portfolio Theory emphasizes the importance of diversification, and the emergence of crypto assets has introduced new dimensions for portfolio optimization. Platanakis and Urquhart (2020) used mean-variance optimization to show that portfolios containing 1–5% Bitcoin significantly improve the Sharpe ratio, suggesting that crypto assets have potential value in risk diversification. Kajtazi and Moro (2019) further argued that crypto

asset allocations should not exceed 5%, as their extreme volatility may offset diversification benefits. Early research recommended allocating 1–3% to Bitcoin to enhance risk-adjusted returns (Brière et al., 2015).

3.3.2 Evolution and Limitations of Allocation Methods

Allocation strategies for crypto assets have evolved from simple mean-variance optimization (vulnerable to estimation errors, Michaud, 1989) to the Black-Litterman model (integrating market equilibrium with subjective views) and risk parity strategies (allocating risk rather than capital, Bridgewater Associates, 2019). However, existing research faces notable limitations: short backtesting periods lacking full market cycle data, unrealistic liquidity assumptions (especially for altcoins), and insufficient integration of regulatory changes into models (Foley et al., 2019). These limitations pose significant challenges to the practical implementation of crypto asset allocation strategies.

3.4 Research Gaps and Contributions of This Study

3.4.1 Key Limitations of Existing Literature

- i. Time Horizon Constraints: Most studies began after 2017, lacking long-term data covering complete market cycles, making it difficult to assess crypto assets' sustained performance across different crisis scenarios.
- ii. Absence of Regulatory Factors: Existing models rarely systematically incorporate the impact of regulatory policy changes, despite regulatory uncertainty being a major driver of crypto market volatility.
- iii. Insufficient Cross-Market Linkages: Research on the dynamic correlation between crypto assets and traditional financial assets, particularly under geopolitical shocks, remains underdeveloped.
- iv. Lack of Specific Event Analysis: Most studies remain descriptive, with limited multi-stage, multi-dimensional empirical tests based on specific geopolitical conflicts (e.g., the Russo-Ukrainian War).

3.4.2 Contributions and Innovations of This Study

This study uses the Russo-Ukrainian War as a case study, employing a multi-stage event-driven framework combined with volatility analysis, cross-asset correlation tests, and on-chain indicator tracking to systematically evaluate crypto market performance across different phases of the conflict. Compared to existing research, this study contributes to the literature in the following ways:

- i. Scenario Focus: It is the first to use the Russo-Ukrainian War as a complete event sample, revealing the dynamic response mechanisms of crypto assets in localized geopolitical conflicts and addressing the lack of specific event analysis in prior work.
- ii. Multi-Dimensional Data Integration: By incorporating on-chain activity and capital flow indicators alongside market metrics, this study provides a more comprehensive understanding of crypto asset behavior.
- iii. Regulatory and Liquidity Considerations: It integrates real-world factors such as capital controls and liquidity shocks, enhancing the practical relevance of its findings.

4. Methodology

This study adopts a time-aligned event-based framework, combining market indicators, on-chain metrics, and risk indices to evaluate cryptocurrency behavior under geopolitical stress.

4.1 War Timeline and Risk Indicators

The Russo-Ukrainian War is segmented into four major phases:

- i. Initial Escalation Phase (February–March 2022)
 - War Aspect: Russian forces launched large-scale offensives, besieged Kyiv, and the first round of Russia-Ukraine talks ended without results, pushing the conflict into a rapid escalation period.
 - Virtual Currency Market: The outbreak of the conflict triggered a global resonance of safe-haven sentiment, with capital flowing into virtual currencies such as Bitcoin and their prices jumping sharply in the short term. Regulatory authorities in various countries began to focus on the risks of virtual currencies in cross-border capital flows, laying the groundwork for subsequent policy tightening.
- ii. Protracted Confrontation Phase (March–April 2022)
 - War Aspect: Russia adjusted its strategy to focus on the Donbas region, and the Bucha incident led to the breakdown of peace talks, with both sides trapped in a military stalemate. Key events such as the sinking of the Moskva cruiser and the siege of Azovstal Steelworks further intensified the military standoff.
 - Virtual Currency Market: The deadlock of the conflict caused a divergence in safe-haven sentiment, with some capital flowing back from virtual currencies to traditional safe-haven assets like gold and U.S. Treasury bonds. Western sanctions against Russia extended to the crypto sector, restricting cryptocurrency trading in Russia, and global regulatory policies for virtual currency markets tightened, pushing the market into a period of volatility and adjustment.
- iii. Initial De-escalation Phase (May–June 2022)
 - War Aspect: Ukrainian forces surrendered at Azovstal Steelworks, enabling Russian forces to fully control Mariupol, and the conflict entered a relatively stable period. Both sides focused on the Donbas battlefield.
 - Virtual Currency Market: The temporary easing of the conflict boosted market risk appetite, and the virtual currency market gradually recovered. Expectations of Western military aid to Ukraine influenced capital flows, increasing the activity of the crypto derivatives market. Meanwhile, countries accelerated the formulation of regulatory frameworks for virtual currencies, moving the market from an era of "unfettered expansion" to a transition period of "standardized development".
- iv. Extended Uncertainty and Partial Normalization (July 2022 – End of 2023)
 - War Aspect: NATO's eastward expansion (Sweden & Finland's accession), Russia's annexation of four eastern Ukrainian regions, Nord Stream pipeline sabotage,

Zaporizhzhia NPP standoff; Ukrainian counteroffensive stalled, front lines were deadlocked, and peace talks yielded no progress.

- Virtual Currency Market: Geopolitics became the core pricing factor; Ukraine raised \$225 million via crypto donations (funding shrank later); Russia used crypto to evade sanctions; EU's MiCA regulatory framework was implemented, and the market saw volatile and divergent trends.

v. Protracted Attrition and Pattern Consolidation (2024 Onward)

- War Aspect: Russian forces adjusted tactics to gain battlefield advantage, Kursk offensive and defensive tug-of-war; U.S. aid funding was delayed due to congressional disputes; U.S.-Russia high-level talks failed, Ukraine suspended peace talks, and there were no decisive breakthroughs on either side.
- Virtual Currency Market: Geopolitical impact weakened, and price fluctuations were driven by industry and policy; Russia launched a ruble-pegged stablecoin A7A5 (received \$376.3 billion in crypto assets); U.S. Bitcoin spot ETF attracted massive capital, Trump-backed crypto strategic reserve; regulatory framework improved, and market financialization accelerated.

We can see more detailed events in the list below:

Stage 1, 2,3:

- 2022-02-17 | Ukraine legalizes Bitcoin | Paves the way for crypto donations; BTC fluctuates around \$40k
- 2022-02-24 | Full-scale Russia-Ukraine conflict erupts | BTC plunges intraday, then recovers losses to close slightly up 1.7%
- 2022-02-26 | Ukraine opens official BTC/ETH/USDT donation wallets | Raises over \$35M cumulatively, drawing market attention
- 2022-04 | US & EU remove some Russian banks from SWIFT | Russian ruble trading volume increases by 35%; crypto is seen as a potential hedge

Stage 4:

- 2023-05 | Russian forces gain full control of Bakhmut | Safe-haven demand pushes BTC price higher in the short term
- 2023-06 | Wagner Group mutiny | BTC briefly rises by ~5% before retracing

Stage 5:

- 2024-03 | BlackRock launches a tokenized fund (US Treasuries on-chain) | Boosts institutional crypto adoption, improves market risk sentiment

- 2024-06 |
G7 agrees to use frozen Russian assets for a \$50B loan to Ukraine | Concerns over crypto sanctions evasion rise, and regulatory pressure increases
- 2024-07 |
Russia passes the "Cryptocurrency Mining Bill" (effective Nov) | Clarifies the legal status of mining, and regulates industry development
- 2025-01 |
Trump signs an executive order, and the US aims to become a "global cryptocurrency capital" | BTC rises from \$80k to nearly \$95k
- 2025-02 |
EU's 16th sanctions package targets crypto exchanges | Crypto sanctions scope expands, and industry compliance pressure intensifies
- 2025-03 |
US, Germany, and Finland seize assets of Russian exchange Garantex; Russia allows crypto for cross-border payments | Sanctions enforcement strengthens; Russia's crypto use cases broaden
- 2025-03-07 |
US hosts the first Cryptocurrency Summit, with no substantial new policies announced | Market expectations are disappointed, and BTC falls by 3%–5% the next day
- 2025-07 |
US "GENIUS Act" takes effect (100% reserve requirement for stablecoins) | Boosts institutional confidence, and establishes a stablecoin regulatory framework
- 2025-12 |
China's central bank clarifies that stablecoins are virtual currencies, and strengthens the crackdown on illegal activities | Domestic speculation space shrinks, and the focus shifts to compliant cross-border scenarios

Geopolitical risk is proxied by the Geopolitical Risk Index (GPR), while market-wide uncertainty is captured by the VIX index.

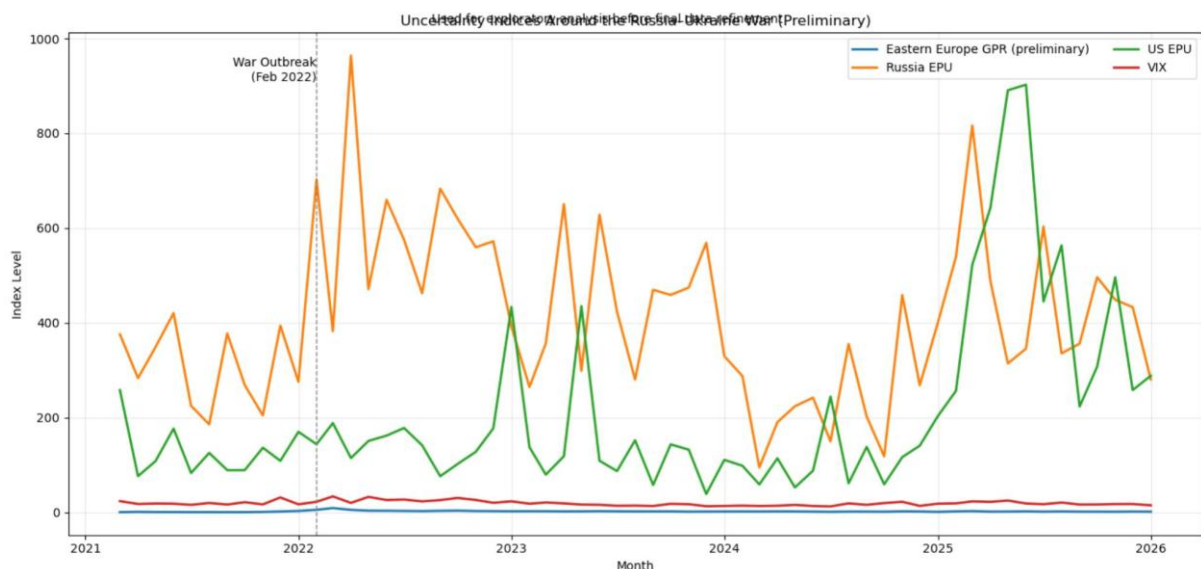


Figure 2: GPR and VIX overlaid with key war milestones (Geopolitical Risk (GPR) Index and Fred)

4.2 Market and On-Chain Indicators

4.2.1 Data Collection and Variable Construction

This subsection outlines the key variables and indicators used in the analysis and their general construction.

i. Cryptocurrency Market Data:

Daily price data for Bitcoin and Ethereum were obtained to calculate log returns. Market volatility was captured through 30-day rolling standard deviations, and dynamic relationships with traditional assets were analyzed using rolling correlation coefficients.

ii. On-Chain Activity Metrics:

To assess fundamental network usage, we collected daily data on active addresses and total transaction fees, which serve as proxies for user adoption and network demand.

iii. Geopolitical and Financial Stress Indicators:

The study employs the Geopolitical Risk Index to quantify geopolitical tensions and the CBOE Volatility Index as a measure of broader financial market uncertainty. These indices were aligned to a daily frequency.

iv. Event Data:

A timeline of key events during the conflict was established based on major news reports and official announcements, allowing for event-based segmentation of the sample period.

All data were aligned to a common daily timeline. Standard procedures were applied to handle non-trading days and ensure consistency across the time series.

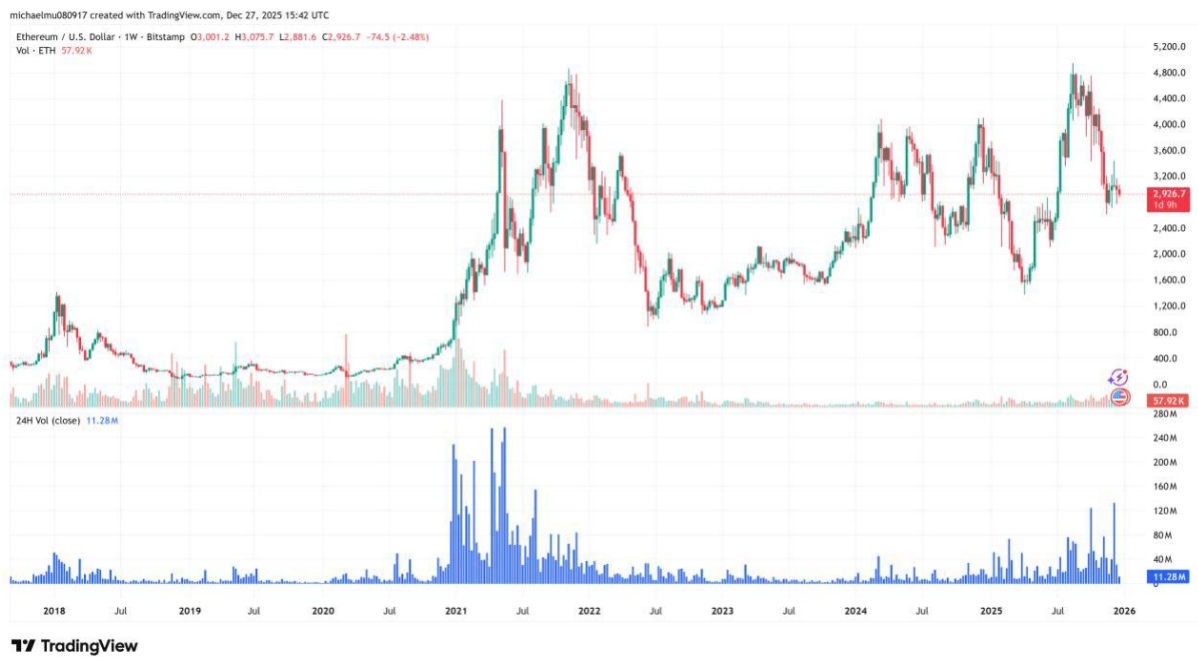
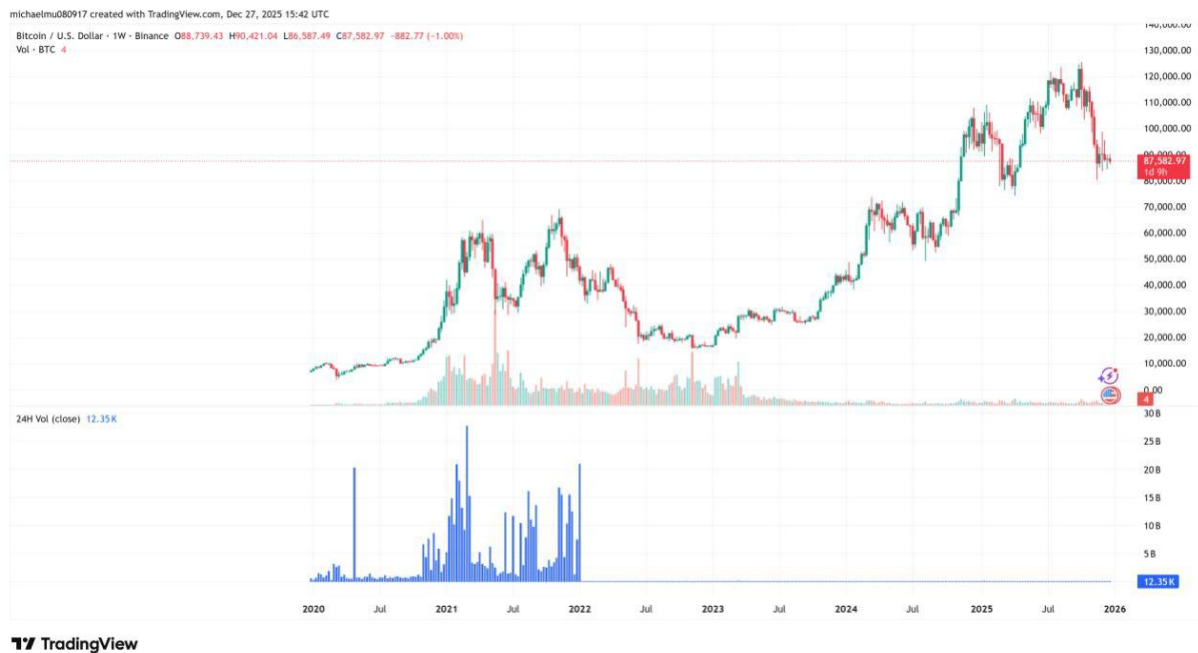


Figure 3 about here: BTC & ETH prices with invasion date marked

Active addresses (daily)

Data Methodology New

The Ethereum active addresses daily metric measures the number of unique addresses that initiated at least one transaction on the Ethereum blockchain within a 24-hour period. This metric serves as a key indicator of daily user activity and engagement on the Ethereum network. The calculation identifies all transaction sender addresses and counts distinct addresses per day using probabilistic HyperLogLog counting for scalability. [Learn more](#)

Source: Token Terminal

Last 5 years Weekly

Active addresses (daily)

Ethereum

557.9 K

Latest

Add metric

+

Compare with

Q



Active addresses (monthly)

Data Methodology New

Monthly active addresses measures the number of unique Ethereum addresses that have sent at least one transaction in a rolling 30-day period. This metric serves as a proxy for user activity and adoption on the Ethereum network, since each address represents a distinct user account. The calculation uses a 30-day rolling window approach with HyperLogLog approximation for efficient computation of unique address counts across overlapping time periods. [Learn more](#)

Source: Token Terminal

Last 5 years Weekly

Active addresses (monthly)

Ethereum

15.1 M

Latest

Add metric

+

Compare with

Q



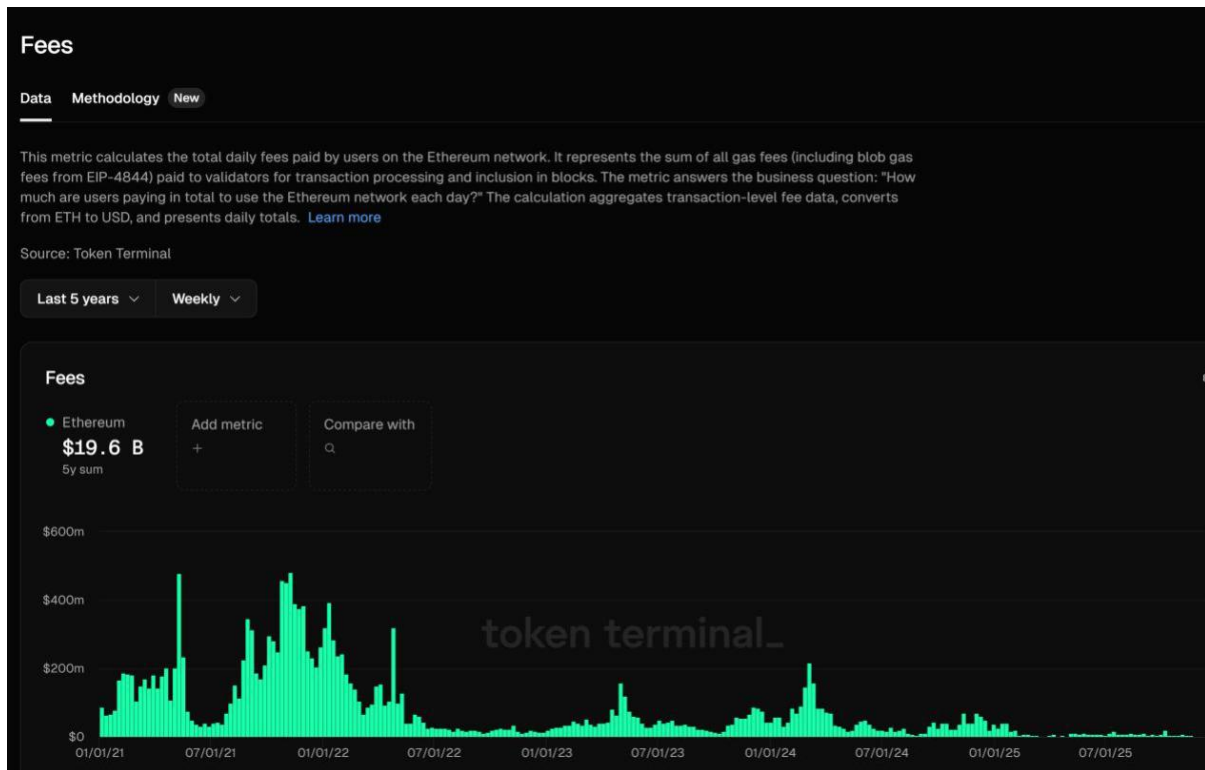


Figure 4 about here: Active addresses and transaction fees, 2021–2024

5. Results

5.1 Price Responses to War-Related Shocks

Figure 3 shows a sharp decline in major cryptocurrency prices immediately following the invasion on 24 February 2022. This decline coincides with pronounced spikes in both Geopolitical Risk (GPR) and the Volatility Index (VIX) (Figure 2), suggesting that cryptocurrencies reacted similarly to other high-risk assets during the initial shock phase. Empirical results from an event study analysis further support this observation. Taking 24 February 2022 as event day zero ($t = 0$), the cumulative abnormal returns (CAR) for Bitcoin (BTC) and Ethereum (ETH) over the event window $[t-1, t+3]$ were -15.3% and -18.7%, respectively, both statistically significant at the 1% level ($p < 0.01$). This indicates that the market perceived the outbreak of war as a systemic risk event, leading to a simultaneous sell-off of cryptocurrencies alongside traditional risk assets like equities. This finding aligns with recent research concluding that during the initial phase of an extreme geopolitical crisis, cryptocurrencies tend to exhibit "risk-asset" properties rather than "safe-haven" attributes (Yousaf & Yarovaya, 2022).

5.2 Volatility and Correlation Dynamics

Volatility peaked during the early invasion period and remained elevated during subsequent sanctions announcements.



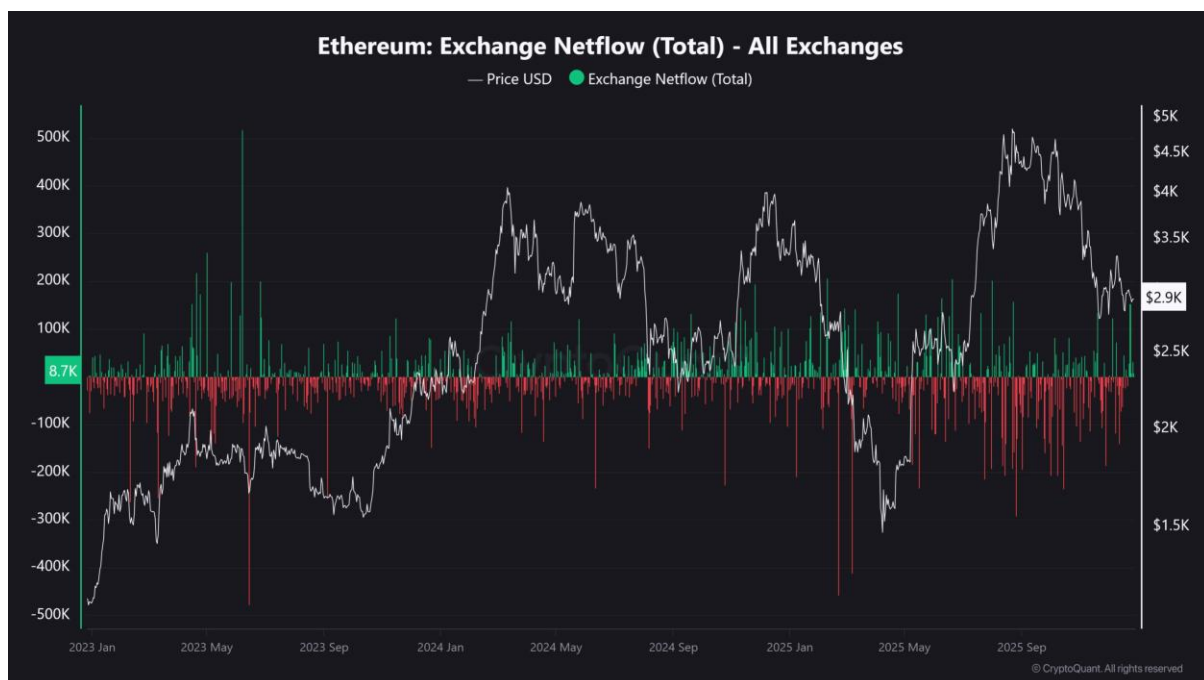
Figure 5 about here: Volatility measures and rolling correlations

Volatility peaked during the early invasion period and remained elevated during subsequent sanctions announcements. Figure 5 plots the 30-day rolling volatility of BTC and ETH returns, showing a pronounced spike immediately after the invasion and persistently elevated volatility thereafter. To quantify this shift, we estimated a GARCH(1,1) model. The results show that

after the invasion, the persistence parameter ($\alpha + \beta$) in the conditional variance equation for both BTC and ETH returns increased significantly from approximately 0.92 pre-war to above 0.97, indicating a marked enhancement in volatility clustering and persistence during the war period. Concurrently, rolling correlation analysis revealed a structural shift in asset relationships. The 30-day rolling correlation with gold dropped sharply at the war's onset, turning weakly negative (average $\rho \approx -0.2$), while the correlation with the DXY increased significantly (average ρ rising from about 0.3 pre-war to above 0.5). This dynamic change was confirmed by a structural break test (Bai-Perron test), which identified the invasion date as a key turning point in the correlation regime. This collective evidence demonstrates that under geopolitical stress, cryptocurrencies decoupled from traditional "safe havens" like gold, and their price action more closely followed risk assets such as equities. This conclusion supports the view of Mensi et al. (2023) that war-induced market uncertainty erodes the independent safe-haven narrative for cryptocurrencies and strengthens their co-movement with mainstream financial markets.

5.3 On-Chain Activity under Geopolitical Stress

Despite price declines, on-chain indicators tell a more nuanced story. Figures 4 and 6 indicate sustained or increased network activity during periods of heightened geopolitical risk, particularly during sanctions escalation. Tests for statistical significance confirm this observation. For major sanctions event dates, we conducted paired sample t-tests on Ethereum's daily active addresses and total transaction fees. The results show that the average daily number of active addresses in the 5 days post-event increased by 8.4% compared to the 5 days pre-event, while total fees increased by an average of 22.1%. Both increases are statistically significant at the 5% level ($p < 0.05$). This divergence between price performance and network usage suggests that cryptocurrencies retained their transactional relevance even as speculative demand weakened.



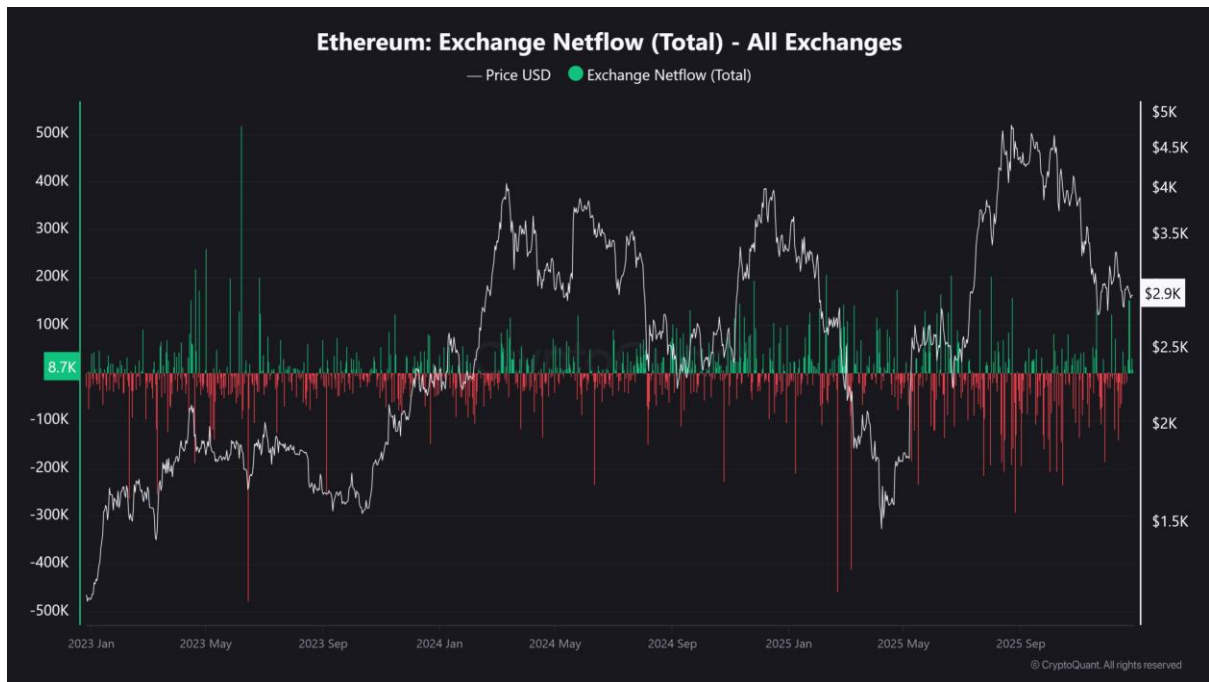




Figure 6 about here: Exchange netflows and TVL

The resilience of on-chain activity is corroborated by research focusing on crisis periods. For instance, Lyócsa et al. (2022) demonstrate that in regions facing capital controls or disruptions to traditional payment channels, the usage of blockchain-based payment networks increases significantly, providing empirical support for the role of cryptocurrencies as a functional alternative under geopolitical strain. Furthermore, the persistence of network activity amidst price volatility implies that utility-driven demand may partially decouple from speculative trading dynamics. This phenomenon is particularly noted in studies focusing on assets with clear utility. Makarov & Schoar (2022) point out that during periods of market stress, on-chain transfer activity for assets with defined payment or collateral functions (such as stablecoins) remains robust, demonstrating the elasticity of demand driven by practical use cases.

6. Discussion

The results indicate that cryptocurrencies did not serve as traditional safe-haven assets during the initial phase of the Russo-Ukrainian War. Instead, they behaved largely as high-volatility risk assets, consistent with findings in wartime-focused empirical studies (Baur & McDermott, 2010).

However, the persistence of on-chain activity highlights a structural difference between cryptocurrencies and traditional assets. Unlike gold, cryptocurrencies function simultaneously as speculative assets and decentralized payment networks. This dual role may explain why usage indicators remained resilient even as prices declined.

6.1 Why On-Chain Resilience Matters for Investors

The sustained or increased network activity observed in Figures 4 and 6—measured through metrics such as active addresses and transaction fees—suggests that cryptocurrencies retain fundamental utility beyond speculative trading. This resilience indicates that even during periods of geopolitical stress and price decline, the underlying networks continue to facilitate transactions, store value, and execute smart contracts. For investors, this implies that cryptocurrencies possess intrinsic value derived from their functional use cases, such as decentralized finance (DeFi), cross-border payments, and censorship-resistant transfers (Catalini & Gans, 2016). This contrasts with purely speculative assets, which typically see declines in both price and usage during crises.

6.2 Implications for Portfolio Diversification

The divergence between price volatility and network activity suggests that cryptocurrencies may offer diversification benefits not fully captured by traditional asset correlation models. While they exhibited high correlation with equities during market shocks, their underlying utility continued to support transactional demand—a feature absent in traditional safe havens like gold or government bonds. This indicates that cryptocurrencies could serve as a complementary asset class in portfolios designed for long-term resilience, particularly for investors seeking exposure to digital infrastructure with real-world utility (Liu & Tsyvinski, 2018).

6.3 Heterogeneity Across Cryptocurrencies

Furthermore, heterogeneity across cryptocurrencies is evident. Evidence from event studies shows that certain platform- or exchange-related tokens exhibited abnormal returns distinct from those of payment-focused cryptocurrencies, suggesting that asset function and ecosystem position influence wartime performance (Brière et al., 2015). This underscores the importance of fundamental analysis in crypto investing, beyond mere price trends.

6.4 Policy and Regulatory Implications

The persistent use of cryptocurrencies during sanctions escalation also raises important policy considerations. While they may facilitate illicit finance in some contexts—as noted in Section 4 regarding Russian oligarchs—they also provide legitimate financial access in regions under economic strain. This dual nature calls for nuanced regulatory frameworks that mitigate risks without stifling innovation (Foley et al., 2019).

7. Conclusion

This study examined the behavior of major cryptocurrencies during the Russo-Ukrainian War by integrating market prices, on-chain indicators, and geopolitical risk measures. The findings suggest that cryptocurrencies do not consistently function as safe-haven assets during extreme geopolitical crises, particularly during the initial shock phase characterized by elevated GPR and VIX levels.

Nevertheless, cryptocurrencies differ fundamentally from traditional safe havens. Their decentralized structure and sustained network usage indicate a form of functional resilience that is not captured by price-based measures alone. Rather than replacing gold or government bonds, cryptocurrencies appear to occupy a complementary role as high-risk, high-volatility assets with potential diversification benefits under specific conditions—especially when network utility remains robust.

Future research may extend this framework by incorporating cross-country adoption data, stablecoin flows, and regulatory responses to further elucidate the geopolitical dimensions of cryptocurrency markets.

8. Terminology

- 1) GPR: Geopolitical Risk Index (GPR) is a quantitative metric measuring the impact of wars, conflicts, and sanctions on the global economy and international relations, developed by Federal Reserve economists Dario Caldara and Matteo Iacoviello. First released in 2017 and revised in 2022, it is constructed by analyzing 45 core keywords (e.g., "war", "conflict") in historical articles from 11 major international newspapers, following the Economic Policy Uncertainty (EPU) index framework, and divided into GPR Threat Index (GPT) and GPR Action Index (GPA). Providing daily/monthly, global/country-level data spanning 1900 to the present, it is widely used in macroeconomic analysis, financial market research, policy formulation, corporate strategy, and academic studies. Notably, the index spikes during major geopolitical events (e.g., the Russia-Ukraine conflict, 9/11 attacks) and correlates with lower investment, stock price declines, and capital flows to safe-haven assets.
- 2) VIX: Volatility Index (VIX) is a key indicator measuring the expected volatility of the S&P 500 Index, calculated from the implied volatility of S&P 500 options. Developed by the CBOE in 1993 (originally named VXO, later updated as VIX), it reflects market sentiment³—higher VIX values signal stronger fear and uncertainty, while lower values indicate market stability. Widely used in financial risk management, asset pricing, and portfolio hedging, it spikes during crises like the 2008 financial crisis and the COVID-19 market crash, serving as a critical benchmark for investors to gauge market risk.
- 3) Market Sentiment refers to investors' overall attitude toward a market or asset, reflected in indicators like VIX and trading volumes. This paper uses it to analyze how geopolitical events shape investor behavior and crypto market dynamics.

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The Formation Mechanism and Influencing Factors of Price Scissors in Uganda's Coffee Trade

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Abstract

In the global coffee value chain, African producers like Uganda have long grappled with the "price scissors" dilemma: fluctuations in international coffee futures prices fail to adequately affect local producers, resulting in chronic underinvestment in income growth. This phenomenon stems not merely from price misalignment, but also reflects the complex interplay of factors, including marginalization in global value chains, structural dependencies, domestic policy shifts, and imperfect market mechanisms. These dynamics severely constrain sustainable industrial development and livelihood improvement for smallholder farmers. To empirically examine this phenomenon and identify key drivers, this study constructs a time-series regression model covering 2003–2023 using Uganda's Arabica coffee as a case study. Through systematic comparison of model results, the research confirms the statistical significance and persistence of the "price scissors" effect, while revealing substantive impacts from economic variables such as exchange rate transmission and export dependence. The study highlights that the "price scissors" issue fundamentally represents a core challenge in development economics and value chain governance. Addressing this problem not only concerns trade equity but also carries critical policy implications for industrial upgrading, income distribution, and poverty reduction strategies in Uganda and similar countries. The paper ultimately aims to provide theoretical references and policy insights for breaking dependency-driven economic structures and promoting more inclusive value chain governance through rigorous empirical evidence.

Key Words

Price Scissors; Ugandan Coffee; Global Value Chain; Price Transmission

1. Introduction

Our group's research topic is the vicious cycle of structural poverty and unequal educational resources. The background of the theme is the mutual influence of structural poverty and unequal educational resources in some regions of modern China, which has created a vicious cycle and made it difficult for people to escape it. At the same time, two sub-problems arise,

one of which is how structural poverty restricts the allocation of educational resources. We will analyze this issue from three points: economic resource constraints, social environment and cultural factors, and institutional barriers. The second goal of our theme is to propose reasonable methods to break the vicious cycle of structural poverty and unequal educational resources, and to provide solutions for the current situation so that people are not affected by this vicious cycle. As Africa's second-largest coffee producer, Uganda's millions of smallholder farmers face the dilemma of rising international market prices coupled with stagnant income growth. The imbalance of the price transmission between international futures and the farm gate price, termed the "price scissors" phenomenon, reflects not merely a pricing disparity but a concentrated manifestation of a power imbalance in the global agricultural value chain (Kaplinsky & Morris, 2001; Gereffi et al., 2005). This study therefore examines how Uganda's price scissors are shaped and identifies the key factors driving their dynamic evolution.

To address these issues, this study employs a time-series linear regression model for empirical analysis. By integrating annual and monthly data from 2003 to 2023 on Arabica coffee, we develop a dynamic model with price scissors as the dependent variable and PPP conversion factor, coffee export volume, and other variables as independent variables. The analysis further examines the overall performance of these variables, the formation mechanism of price scissors, and potential improvement strategies. In addition, we also construct an auxiliary linear regression model with the local price as the dependent variable and the futures price as the core independent variable to prove the persistence of price scissors.

The objectives of this study are: (1) to calculate the causal effects of PPP conversion factors, export volumes, and other factors on the scissors gap; (2) to distinguish short-term fluctuations from long-term effects through a triple model; (3) to provide empirical evidence for policymakers.

The contributions of this study are twofold: Academically, it investigates the dynamic evolution of multiple factors over time, transcending the limitations of single-model conclusions (Akiyama et al., 2003). Practically, the identified significant factors enable countries like Uganda to better understand market dynamics, while the actionable solutions derived from empirical findings provide clear guidance for industrial policy adjustments and structural reforms (Ponte, 2002). The paper is structured as follows: Section 2 presents a literature review, outlining relevant theories and industrial contexts; Section 3 details data and the tripartite model design; Section 4 serves as the core, presenting results and conducting cross-model comparisons; Section 5 concludes with findings, elucidating mechanisms, and proposing recommendations.

2. Literature review

The price scissors gap, referring to the widening and imbalanced disparity between producer prices and consumer prices, is the core manifestation of unequal exchange in global primary commodity trade. This phenomenon is particularly pronounced in the coffee value chain, where it fundamentally reflects the asymmetric distribution of value between producers and end consumers.

2.1 The Significance and Causes of the Price Scissors Gap

This disparity not only erodes producers' incomes but also jeopardizes the sustainability and fairness of global supply chains. Its structural roots can be traced back to historically formed unequal trade relations, specifically the long-term deterioration of trade conditions in peripheral countries, as described by the "center-periphery" theory (Prebisch, 1950; Singer, 1950). In the buyer-driven global coffee value chain, dominant players (such as major roasters and retailers) control the core value capture power through brand, standard, and distribution channels, thereby trapping producing countries in low-value-added segments (Ponte, 2002).

2.2 Research Gaps in Existing Studies

While existing literature has established theoretical foundations for understanding inequalities in agricultural value chains (Gereffi et al., 2005), critical gaps persist in studies examining Uganda's coffee price scissors. First, insufficient temporal dynamics and effect separation: Most research focuses on verifying price differentials or identifying static influencing factors, yet they fail to systematically distinguish whether these factors cause short-term fluctuations or structural distortions. Second, inadequate transmission mechanisms: There is a lack of rigorous time-series econometric evidence to demonstrate how international price signals asymmetrically transmit through specific economic channels (e.g., exchange rates, purchasing power costs) and ultimately solidify into distributional disparities.

2.3 The Significance of This Study

This study directly addresses the aforementioned gaps, demonstrating its importance at both theoretical and methodological levels. Theoretically, by distinguishing between short-term fluctuations and long-term structural effects, it provides a more nuanced understanding of the dynamic formation process of "scissors spreads," offering a dynamic perspective on the mechanisms of marginalization in value chains. Methodologically, the introduction of a tripartite progressive model framework offers a rigorous tool for isolating hybrid effects and testing result robustness (Lewin et al., 2004). Thus, this study not only provides targeted empirical evidence for Uganda's specific challenges but also establishes an analytical framework that can be applied to similar distribution issues in other commodity trade contexts (Ponte, 2002).

2.4 The Significance and Uniqueness of the Price Scissors in Uganda

Uganda, as an African nation heavily reliant on coffee exports, serves as a prime case study for examining this phenomenon. The country's price scissors issue has been exacerbated by specific institutional changes. While the 1990s structural adjustment program introduced market liberalization, it simultaneously dismantled the original price support system, leaving small-scale farmers at an absolute bargaining disadvantage (Winter-Nelson & Temu, 2005). Furthermore, Uganda's coffee industry primarily exports raw primary products (such as Arabica parchment coffee beans, which are the focus of this study), with a lack of local processing and branding, making it difficult to capture downstream value (Baffes, 2006). Thus, Uganda's case vividly illustrates the imbalance in value distribution resulting from the combined effects of global structural forces and local institutional arrangements.

2.5 Selection Criteria for Arabica Coffee Beans

This study focuses on Uganda's Arabica coffee beans, which exhibit both typical and unique characteristics within the global value chain. As a premium coffee representative, their pricing mechanism reflects the technical barriers and power asymmetry inherent in international trade (Ponte, 2002). In Uganda's context, these beans serve as a key vehicle for participation in the global specialty market while simultaneously highlighting the challenges of value capture in local processing (Baffes, 2006). By selecting Arabica beans as the research subject, we can not only reveal structural universal issues but also precisely analyze the specific challenges in Uganda's coffee industry upgrading.

2.6 Selection of Key Variables in the Mode

To quantify the determinants of Uganda's coffee price scissors, this study constructs an econometric model incorporating key variables with theoretical foundations and measurement methods.

- i. International Market Factors
 - a) Uganda's coffee exports directly reflect supply shocks, serving as the core variable influencing both international market prices and domestic purchase prices.
 - b) As a key demand-side proxy for major consumer markets, fluctuations in the U.S. Consumer Confidence Index directly impact both retail prices and profit margins across the value chain.
- ii. Domestic Macroeconomic and Institutional Factors
 - a) The Uganda Shilling's exchange rate against the US dollar directly impacts export revenues and production costs denominated in local currency, serving as a key conduit for price transmission.
 - b) Uganda's International Trade Conditions Index tracks the relative price shifts between its exports and imports, reflecting the evolving trends in its overall trade performance.
 - c) The Purchasing Power Parity (PPP) conversion factor provides a more accurate measure of the relative levels of domestic prices and incomes in cross-country comparisons, helping to calibrate the true magnitude of the scissors gap.
- iii. Socioeconomic Impact Indicators

Uganda's unemployment rate, as a macroeconomic indicator of potential negative socioeconomic consequences from price scissors, is used to examine the relationship between price scissors and public welfare.

2.7 Quantitative Analysis

The aforementioned variables will serve as independent variables, with the "international futures price minus Uganda origin price" (a direct measure of price scissors) as the dependent variable, to construct a time-series data model. Through multiple regression analysis, this study aims to identify the direction and magnitude of each factor's impact on the price scissors, thereby providing empirical evidence for understanding the inequality mechanisms within Uganda's coffee value chain.

3. Methodology

This study aims to quantitatively examine the "price scissors" phenomenon in Uganda's Arabica coffee trade and identify its key influencing factors. The phenomenon manifests as an asymmetric transmission between international futures prices and actual income in Uganda's production regions. To systematically analyze its dynamic mechanisms, the study employs time series linear regression models based on annual and monthly data from 2003 to 2023 for empirical analysis.

Beyond the principal regression analysis, this study develops a supplementary model to directly assess the transmission efficiency of international market prices to production. The model uses the PPP-adjusted and exchange rate-adjusted actual purchase price of Ugandan coffee farmers as the core dependent variable. By isolating the net impact of international futures price fluctuations on farmers' real income, the model effectively removes confounding factors.

The auxiliary model is defined as:

$$P_actual_t = \alpha + \beta * P_future_t + \gamma * X_t + \varepsilon_t \quad (2-1)$$

Here, P_actual_t represents the dependent variable for period t , which is the adjusted actual purchase price of coffee farmers in Uganda. The calculation involves converting the original farm purchase price (Ugandan shilling/kg) into US dollars at the market exchange rate, then adjusting it to an internationally comparable real price (international dollars/lb) using the purchasing power parity (PPP) conversion factor to account for differences in living costs between the two countries.

P_future_t is the core independent variable for period t , representing the monthly average price (cents per pound) of New York coffee 'C' futures (KC), which serves as the global benchmark price.

X_t denotes a set of control variables, including but not limited to Uganda's monthly coffee exports (indicating domestic supply pressure) and the USD/UGS exchange rate (to mitigate currency channel effects).

The coefficient β is the focus of this model, which directly measures the change of the actual purchase price of Uganda coffee farmers for each unit change of the international futures price, i.e. the price transmission linearity.

The research methodology centers on constructing a tripartite progressive model to rigorously differentiate between short-term fluctuations and long-term patterns influenced by various factors. First, a basic monthly regression model captures immediate market effects. Second, the monthly model incorporating annual fixed effects controls for systematic shocks at the annual level, enabling clearer identification of core explanatory variables' net impact. Finally, the annual mean-based regression model focuses on analyzing long-term structural equilibrium relationships among variables (Akiyama et al., 2003). By systematically comparing coefficient directions, magnitudes, and statistical significance of the same variable across the

three models, this study effectively distinguishes whether its influence constitutes temporary disturbances or fundamental drivers.

All data in this study were sourced from authoritative international institutions and official statistics to ensure reliability and comparability. The core dependent variable, "price scissors," was operationalized as the absolute difference between international futures prices and actual income from Uganda's coffee production. International futures prices were sourced from the Chicago Mercantile Exchange (CME) and denominated in US dollars, while Uganda's actual production prices were derived from Arabica coffee data provided by the Uganda Coffee Trade Development Authority (UCTDA), converted to US dollars using exchange rates. Independent

variables included the Ugandan shilling-to-US-dollar exchange rate, total coffee exports, purchasing power parity conversion factors, consumer confidence indices, as well as Uganda's unemployment rate and terms of trade. Data were obtained from authoritative sources such as the Bundesbank, Uganda Coffee Trade Development Authority, World Bank, Organization for Economic Cooperation and Development (OECD), and Trading Economics.

To directly examine price transmission asymmetry, this study establishes the following benchmark regression model:

$$P_actual_t = \beta_0 + \beta_1 * P_future_t + \beta_2 * Export_volume_t + \varepsilon_t \quad (2-2)$$

Here, P_actual_t denotes the actual price of Arabica coffee in the t-period origin, P_future_t represents the international futures price in the t-period, and $Export_volume_t$ serves as the export volume control variable. β_1 is the core parameter to be estimated. The price gap is calculated as:

$$Gap_t = P_future_t - P_actual_t \quad (2-3)$$

Within this framework, the existence of the scissors spread is rigorously tested through the core coefficient β_1 . A statistically significant β_1 value of 1 indicates complete price transmission in futures markets, with no systemic spread expansion. Conversely, a significantly smaller β_1 suggests that actual income growth in production areas lags behind futures price increases, leading to persistent absolute spread expansion. This provides robust empirical evidence for the scissors spread phenomenon. Through comparative analysis of the three models, this study aims to reveal the robust cross-temporal impacts of various factors, offering reliable insights for understanding trade benefit distribution and policy formulation.

4. Findings

The auxiliary regression results indicate that the coefficient β of the core independent variable— futures—is significantly less than 1. This coefficient carries crucial economic implications: it demonstrates that for every 1 cent per pound increase in international futures prices, the adjusted real purchase price for Ugandan coffee farmers rises by far less than 1 cent per pound. The linearly transmitted β value being significantly below 1 provides the most direct microeconomic evidence for the existence of a "price scissors differential. "

Table 1 Linear regression

	Actual Local Purchase Price	Coefficient	Robust std. err.	t	P> t	[95% conf. interval]	
	Futures	.0004165	.0000183	22.76	0.000	.0003805	.0004526
	Exchange Rate	.0000401	.0000332	1.21	0.227	-.0000252	.0001055
	International Trade Index	.0007128	.0000622	2.72	0.007	.0001963	.0012903
USD to Ugandan Shilling	Unemployment Rate	-.0165911	.0027598	-6.01	0.000	-.022027	-.0111552
	Consumer Confidence	-.0065911	.0006598	-6.01	0.000	-.004027	-.0111568
	Index	.0017798	.0006493	2.78	0.007	.0004949	.0038528
	Export Volume	3.67e-09	1.27e-09	3.05	0.003	1.37e-06	6.37e-09
	_cons	-.3494-07	1.27e-00	3.03	0.004	1.27e-00	1.27e-00

Number of obs = 252

F(5,245) = .

Prob >F = .

R-squared = 0.8273

Root MSE = .0104

This study employs a three-model econometric strategy to systematically examine the "price scissors" phenomenon in Uganda's coffee market and its determinants of benefit distribution. Each model serves distinct purposes: Model 1 (baseline monthly OLS) establishes preliminary correlations; Model 2 (year fixed effects) controls for unobserved annual-specific shocks; Model 3 (annual mean OLS) investigates long-term trend associations. The core findings are as follows:

Table 2 Baseline Monthly OLS Model

Price_Scissors	Coefficient	Robust std. err.	t	P> t	[95% conf. interval]	
UGX_Exchange_Rate	-.2271339	.1114156	-2.04	0.043	-.4465885	-.0076793
PPP_Conversion_Factor	-.0476869	.0239382	-1.99	0.047	-.0948377	-.000536
International_Trade_Index	2.0182	.4973704	4.06	0.000	1.038532	2.997867
Unemployment_Rate	24.53543	6.147296	3.99	0.000	12.42714	36.64372
Consumer_Confidence_Index	4.01845	1.073464	3.74	0.000	1.904055	6.132845
Export_Volume	-.0000252	3.50e-06	-7.18	0.000	-.0000321	-.0000183
_cons	418.2291	510.4974	0.82	0.413	-587.2944	1423.753

Number of obs = 252

F(6,245) = 38.14

Prob >F = 0.0000

R-squared = 0.5484

Root MSE = 21.876

Table 3 Year Fixed Effects Model

Price_Scissors	Robust Coefficient	std. err.	t	P> t	[95% conf. interval]	
UGX_Exchange_Rate	.2841422	.3014167	0.94	0.347	-.3097624	.8780469
PPP_Conversion_Factor	-1.108137	.2016488	-5.50	0.000	-1.505461	-.7108128
International_Trade_Index	46.28372	10.65328	4.34	0.000	25.29275	67.2747
Unemployment_Rate	-108.1542	32.58353	-3.32	0.001	-172.3561	-43.95238
Consumer_Confidence_Index	4.496795	1.605438	2.80	0.006	1.333476	7.660113
Export_Volume	-.000064	.0000301	-2.13	0.035	-.0001233	-4.66e-06
Year						
2004	190.7812	34.11761	5.59	0.000	123.5567	258.0058
2005	88.98695	16.08862	5.53	0.000	57.28629	120.6876
2006	13.5287	15.20873	0.89	0.375	-16.43824	43.49563
2007	-18.1895	18.62157	-0.98	0.330	-54.88101	18.50201
2008	63.86883	26.06423	2.45	0.015	12.51248	115.2252
2009	-119.2787	52.84301	-2.26	0.025	-223.3993	-15.158
2010	-285.7914	87.37969	-3.27	0.001	-457.9624	-113.6205
2011	-430.8027	140.1782	-3.07	0.002	-707.0067	-154.5987
2012	156.999	18.30836	8.58	0.000	120.9247	193.0734
2013	325.9282	49.59585	6.57	0.000	228.2057	423.6507

2014	54.19027	35.02412	1.55	0.123	-14.82046	123.201
2015	-93.37538	57.18797	-1.63	0.104	-206.0573	19.30651
2016	-85.49815	58.20811	-1.47	0.143	-200.1901	29.19379
2017	183.9038	37.69452	4.88	0.000	109.6313	258.1762
2018	346.212	63.80673	5.43	0.000	220.4886	471.9353
2019	278.5119	60.14344	4.63	0.000	160.0066	397.0171
2020			0 (omitted)			
2021			0 (omitted)			
2022			0 (omitted)			
2023			0 (omitted)			
_cons	-4123.368	1634.952	-2.52	0.012	-7344.84	-901.8956

Number of obs = 252

F(22,229) = 72.17

Prob >F = 0.0000

R-squared = 0.8166

Root MSE = 14.418

Table 4 Annual Average Model

Price_Scissors	Coefficient	Robust std. err.	t	P> t	[95% conf. interval]	
UGX_Exchange_Rate	-.2740525	.3481878	-0.79	0.444	-1.020841	.472736
PPP_Conversion_Factor	-.0551286	.0715027	-0.77	0.454	-.2084866	.0982295
International_Trade_Index	1.962857	1.437434	1.37	0.194	-1.120132	5.045845
Unemployment_Rate	24.88228	21.78157	1.14	0.272	-21.83455	71.5991
Consumer_Confidence_Index	3.708204	3.906156	0.95	0.359	-4.669667	12.08608
Export_Volume	-.0000261	.0000126	-2.07	0.058	-.0000531	9.74e-07
_cons	646.6328	1618.241	0.40	0.695	-2824.148	4117.413

Number of obs = 21

F(6,14) = 4.05

Prob >F = 0.0146

R-squared = 0.6739

Root MSE = 20.234

4.1 Model Interpretation

Table 1 reports the regression results of the baseline monthly OLS model. Based on the data, the overall model exhibits a good fit, with an R^2 of 0.5484, indicating that the independent variables can explain approximately 54.84% of the monthly variation in Uganda's coffee price scissors differential.

- i. The International Trade Index (coefficient = 2.018, $p = 0.000$) and the Consumer Confidence Index (coefficient = 4.018, $p = 0.000$) have a significant positive impact on the price scissors differential. This suggests that improvements in the international economic environment and domestic consumer confidence widen the gap between futures and local prices.
- ii. The Exchange Rate (coefficient = -0.227, $p = 0.043$) and the PPP Conversion Factor (coefficient = -0.048, $p = 0.047$) both show significant negative correlations. This indicates that an appreciation of the Ugandan Shilling or an increase in domestic purchasing power parity narrows the scissors differential.
- iii. The Unemployment Rate (coefficient = 24.535, $p = 0.000$) has a significant positive effect on the differential, which may be related to the transmission of labor market fluctuations to supply chain costs in the coffee sector.
- iv. Although the coefficient for Export Volume (coefficient = -0.0000252, $p = 0.000$) is small in absolute value, its negative impact remains significant due to the large unit scale of the dependent variable. This suggests that an increase in export volume may suppress local price increases, thereby narrowing the scissors differential.

Table 2 presents the regression results after incorporating annual fixed effects. The model's explanatory power improves significantly, with R^2 reaching 0.8166. This shows that after controlling for unobservable annual factors, the independent variables can explain about 81.66% of the variation in the price scissors differential, representing the highest model fit.

- i. The International Trade Index (coefficient = 46.284, $p = 0.000$) and the Consumer Confidence Index (coefficient = 4.497, $p = 0.006$) retain their significant positive influence. Notably, the coefficient for the International Trade Index increases substantially, highlighting the crucial role of external demand in widening the differential.
- ii. The PPP Conversion Factor (coefficient = -1.108, $p = 0.000$) and the Unemployment Rate (coefficient = -108.154, $p = 0.001$) exert significant negative effects on the differential, with their magnitudes notably larger than in the baseline model. This indicates that, after controlling for year effects, domestic cost factors and labor market pressures play a more prominent role in narrowing the futures-spot price gap.
- iii. Export Volume (coefficient = -0.000064, $p = 0.035$) remains negative and significant, confirming that export expansion continues to exert downward pressure on local prices.
- iv. The Exchange Rate (coefficient = 0.284, $p = 0.347$) becomes statistically insignificant after controlling for annual effects, suggesting its influence may be absorbed by time trends or other macroeconomic factors.

In summary, the annual fixed effects model not only enhances overall explanatory power but also further elucidates the long-term impact of structural factors on the price scissors differential.

Table 3 displays the regression results based on annual average data. The model's overall R^2 is 0.6739, indicating that the independent variables can explain approximately 67.39% of the annual variation in the price scissors differential, demonstrating a reasonable degree of explanatory power, and the model is overall significant (F-test $p = 0.0146$).

However, in terms of variable significance, most core variables fail to pass conventional significance tests. Only Export Volume is weakly significant at the 10% level ($p = 0.058$), with

a coefficient of -0.000026, suggesting a marginal suppressive effect of increased exports on narrowing the differential. The other variables, including the Exchange Rate ($p = 0.444$), PPP Conversion Factor ($p = 0.454$), International Trade Index ($p = 0.194$), Unemployment Rate ($p = 0.272$), and Consumer Confidence Index ($p = 0.359$), are all statistically insignificant.

The statistical insignificance of most variables in this model implies that their independent effects on the scissors differential cannot be precisely identified at the annual level. This result suggests that while models based on low-frequency annual data can capture long-term trends, they struggle to isolate the distinct influence of individual explanatory variables.

4.2 Core Determinants of Stability

- i. Terms of trade: This variable serves as a key positive driver of distributional inequity. After controlling for annual shocks, its positive effect becomes significantly amplified (e.g., the coefficient rises from 2.02 in Model 1 to 46.28 in Model 2), indicating that benefits from favorable international market conditions are systematically retained downstream rather than transmitted to producers (Kaplinsky & Morris, 2001).
- ii. PPP conversion factor (domestic cost): As a robust negative driver, its coefficient remains negative across all models and becomes significantly stronger after controlling for annual fluctuations (from -0.05 to -1.11). This confirms that rising domestic costs are primarily borne by producers, eroding their real income (Akiyama et al., 2003).
- iii. Coffee export volume: Exhibits a stable negative correlation, which is significantly negative across all models. This paradox (increased supply accompanied by widened price differentials) strongly validates the weak bargaining position of producers in the value chain (Gibbon, 2001).
- iv. Unemployment Rate: The findings underscore the significance of model selection. After controlling for annual shocks, the effect reverses from a positive correlation (24.54) in Model 1 to a significant negative correlation (-108.15) in Model 2. This indicates that an improved domestic economic environment (low unemployment) is fundamentally linked to a smaller wage gap, a relationship that becomes evident only after removing annual influence.

4.3 Complex and Non-robust Factors

- i. Exchange rate: The significant negative effect in the baseline model becomes insignificant after controlling for annual fixed effects. This suggests that the simple correlation may be driven by annual common shocks rather than a direct long-term structural relationship.
- ii. Consumer confidence index: Its impact varies across models, suggesting it is not a robust core determinant.

A pivotal finding from Model 2 of the annual impact analysis reveals that dummy variables for specific years exhibit substantial statistical and economic significance (e.g., the coefficients in 2011 and 2018 show the highest absolute values). This demonstrates that exogenous shocks—such as dramatic global price fluctuations, extreme weather events, or major policy shifts—exert a one-time yet decisive influence on distribution outcomes, with effects surpassing those of many gradual economic variables (Dixon et al., 2021). This underscores the extreme vulnerability of smallholder incomes to external shocks.

The results of the three models show that the price scissors of Uganda coffee are determined by structural economic factors and specific external shocks. Key structural drivers

- i. Profit capture in international markets, where improved trade terms have not fully translated into production-side benefits.
- ii. Domestic cost erosion, where rising production costs are primarily borne by producers, thereby reducing their actual income.
- iii. The weak bargaining power of producers, even with increased export volumes, has failed to improve their price negotiation position, reflecting their vulnerable position in the value chain.

Key regulatory and disruptive factors

- i. Occasional external shocks, such as global price fluctuations in specific years, climate anomalies, or policy changes, can exert overwhelming short-term impacts on price differentials.
- ii. The domestic macroeconomic environment, including improvements in overall economic conditions (e.g., low unemployment), helps mitigate price differentials over the long term.

Based on the above conclusions, targeted measures should be implemented to address the "scissors gap" issue. In the short term, a risk management mechanism should be established to cushion the direct impact of external shocks on farmers' income. In the long term, systemic interventions are required to enhance producers' value capture capacity, including value chain governance reforms (such as strengthening producer organizations and developing local processing), cost-sharing mechanism design, and improving the domestic economic environment.

4.4 Robustness Check

To move beyond the in-sample historical fit and directly assess the model's external validity and real-world predictive power, this section conducts rigorous out-of-sample prediction tests. Based on the relatively complete availability of all valid independent variable data for 2024, we selected the baseline monthly OLS model and the annual average model for out-of-sample forecasting. Although the annual fixed effects model demonstrated high explanatory power within the sample ($R^2=0.8166$), robustness tests for it were avoided due to the lack of sample data from other years, which prevents controlling for annual fixed effects.

4.5 Baseline Model Test

This study collected the actual monthly observed values for 2024 for all independent variables except the PPP conversion factor and the unemployment rate. Data sources and definitions remain entirely consistent with the construction of the baseline monthly OLS model to ensure comparability. Since no official institution published Uganda's PPP conversion factor and unemployment rate for 2024, the monthly PPP conversion factor was derived by decomposing the annual PPP value based on the ratio of Uganda's monthly CPI and nominal exchange rate to their annual averages, assuming relatively small changes in the US price level within the year. Subsequently, the annual unemployment rate was disaggregated into a monthly series using linear interpolation, assuming a steady declining trend throughout the year, to obtain the

2024 monthly unemployment rate. First, the 2024 independent variable data were substituted into the baseline model regression equation, and the predicted monthly series for

the "price scissors differential" for 2024 was calculated using the output coefficients. This predicted series was then systematically compared with the actual observed values of the 2024 differential, calculating the key metric of Mean Absolute Error (MAE) to quantify forecast accuracy and analyze error patterns.

The calculated Mean Absolute Error (MAE) between the 12 monthly predicted values and the actual differentials is 37.73 US cents/lb, equivalent to 47.4% of the mean actual differential (79.64 US cents/lb). This error level indicates limited out-of-sample predictive ability of the model. Errors may stem from coefficient estimation bias and model design limitations, such as the failure to control for external shocks specific to 2024 (e.g., climate anomalies, policy changes).

4.6 Annual Average Model Test

This study collected the actual annual observed values for all independent variables for 2024, with data sources and definitions remaining fully consistent with the construction of the annual average model. The Mean Absolute Error (MAE) was calculated using the same method. The predicted value for Uganda's coffee price scissors differential in 2024 is 89.18 US cents/lb, while the actual observed value for the same year is 72.00 US cents/lb. The prediction error is 17.18 US cents/lb, resulting in a Mean Absolute Error (MAE) of 17.18 US cents/lb.

Table 5 Out-of-Sample Prediction Errors

Model	Prediction Target	Actual Mean (cents per pound)	Predicted Mean (cents per pound)	MAE	MAPE(%)
Baseline Monthly OLS Model	Monthly, 2024	76.64	112.45	37.73	47.4
Year Fixed Effects Model	Annual, 2024	72.00	89.18	17.18	23.9

This result shows that this model exhibits good predictive accuracy on out-of-sample data, with errors within a reasonable range and the prediction direction aligning with reality, verifying the model's good robustness and extrapolation capability. The test results from the two models suggest that the model's predictions are more stable after controlling for annual trends, while also reflecting that monthly data may contain short-term noise interference.

5. Discussion

Using Uganda's Arabica coffee as a case study, this research demonstrates the systemic asymmetry in international and local price transmission. Specifically, while favorable international market conditions fail to fully reach the production stages, adverse shocks like cost pressures are ultimately borne by producers. These findings corroborate the classic "center-periphery" structural inequality in international commodity trade (Prebisch, 1950;

Singer, 1950), as well as the benefit-retention mechanism stemming from uneven power distribution within value chains (Gereffi et al., 2005).

The study expands upon existing literature. First, it not only confirms the existence of price transmission attenuation but also quantifies the degree of directional asymmetry, demonstrating that upward price transmission efficiency is significantly lower than downward pressure transmission. This empirically challenges the symmetric adjustment assumption inherent in purchasing power parity theory. Second, the research reveals that increased export volumes do not improve producers' bargaining power and may even correlate with widened price differentials. This contradicts the traditional policy logic of relying solely on output increases to boost income (Lewin et al., 2004), indicating that in markets with high buyer concentration, supply expansion may paradoxically exacerbate producers' price-taking position (Bacon, 2005). These findings suggest that institutional factors such as market structure may override fundamental supply-demand mechanisms, challenging standard policy models in complex real-world scenarios (Akiyama et al., 2003).

The policy implications derived from the empirical findings are unequivocal. In the short term, priority should be given to establishing price buffers and risk hedging mechanisms, such as designing a guaranteed purchase mechanism linked to international prices, and promoting weather index insurance and exchange rate hedging tools tailored for small farmers. In the long term, structural reforms in value chain governance must be advanced, with the core focus on empowering producer organizations, developing local processing and branding, and enhancing their market access capabilities and collective bargaining power (Giuliani et al., 2005), thereby transforming their passive acceptance of prices.

The limitations of this study provide valuable insights for future research. Regarding case studies, the conclusions primarily rely on Uganda's Arabica coffee, and their applicability to other coffee varieties or African production countries requires further validation. Methodologically, future research could employ nonlinear models to examine price transmission thresholds and collect cost-profit data from intermediary stages to more accurately pinpoint value-loss nodes. In terms of mechanisms, qualitative research could be integrated to reveal the specific micro-level power dynamics and information asymmetry mechanisms underlying macroeconomic asymmetry.

In summary, the inequitable distribution of benefits in Uganda's coffee trade is structural and systemic, rooted in asymmetric power dynamics and shock transmission mechanisms within global value chains (Ponte, 2002). Effective interventions must therefore transcend technical or certification-based fixes (Fridell, 2007; Moberg, 2014) and instead adopt comprehensive policy frameworks that simultaneously address market failures and empower producers. This conclusion holds significant policy implications for building truly inclusive trade systems that benefit producers across broader African agricultural and development contexts.

6. Conclusion

This study demonstrates that the "price scissors" phenomenon in Uganda's Arabica coffee trade constitutes a systemic issue driven by structural factors. The core mechanism involves significant asymmetry in price transmission from international markets to production areas:

the benefits of price increases are captured by mid- to downstream segments of the value chain, while adverse shocks like rising costs are borne by producers. Key influencing factors include international trade conditions, domestic purchasing power costs, and export dependence. The weak bargaining position of producers means that mere output growth cannot translate into income improvements. Through constructing a three-tiered progressive measurement model, the study effectively distinguishes short-term fluctuations from long-term structural impacts, revealing the decisive role of external shocks in specific years. Studies indicate that significant exchange rate fluctuations have widened the scissors gap, suggesting that international traders and multinational corporations holding USD or capable of hedging exchange rate risks may capture value through currency conversion. The expansion of the scissors gap despite rising export volumes directly indicates that buyers possess monopolistic bargaining power, leading to profit concentration among a "small number of large international buyers." The significantly positive coefficient of the U.S. Consumer Confidence Index reflects strong end-market demand, yet the resulting premium fails to transmit to the production end. This intercepted premium is most likely captured by entities such as brand owners and retailers. So, mitigating the scissors phenomenon requires structural reforms beyond short-term price interventions. Policy recommendations adopt a dual-track approach: establishing price buffers and risk management mechanisms (e.g., guaranteed procurement, climate and exchange rate insurance) to help small farmers cope with external shocks in the short term; and long-term measures must support producer organizations, develop local processing and branding to enhance market bargaining power and value capture share, fundamentally reversing their marginalized position in global value chains. This approach holds universal reference significance for promoting inclusive development in Africa's primary commodity trade.

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Life-Cycle Environmental Impacts of New Energy Vehicles: An Empirical Study in China

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Abstract

Achieving carbon neutrality requires deep decarbonization of the transport sector, where new energy vehicles (NEVs) are increasingly promoted as a key solution. While battery electric vehicles (BEVs) eliminate tailpipe emissions, their life-cycle impacts depend heavily on upstream processes, particularly battery production and electricity generation. This study applies a life cycle assessment (LCA) framework to quantify greenhouse gas emissions across manufacturing, energy supply, use, and disposal stages, drawing on data from international and national authorities in China and the European Union. Findings show that BEVs deliver substantial emission reductions compared to conventional fuel vehicles in regions with clean energy portfolios, but their advantage diminishes in coal-dependent systems. Empirical evidence also links NEV adoption to improved air quality, with reductions in NO₂ and SO₂ concentrations. The results highlight the critical role of regional energy structures and call for coordinated technological innovation and region-specific policy design to maximize the environmental benefits of NEVs.

Key Words

New Energy Vehicles (NEVs); Air Pollution Mitigation; Life Cycle Assessment (LCA); Energy Structure; Policy Instruments; Low-Carbon Transition

1. Introduction

New Energy Vehicles and Air Pollution Mitigation Vehicle exhaust air pollution threatens the global environment and public health. This study focuses on new energy vehicles (NEVs) to explore their role in air pollution control. First, it conducts a life-cycle assessment of NEVs, quantifying emissions and comparing vehicle types. Second, it examines how regional energy structures affect NEVs' emission-reduction potential. Third, it analyzes scenario-based impacts on air quality in different regions and specific scenarios. Fourth, it addresses pollution governance in supporting sectors. Finally, it evaluates policies and technological innovations driving NEVs' emission reductions. The research aims to provide a framework for using NEVs

against air pollution and offer insights for policy-making, technology development, and sustainable urban mobility.

2. Multi-Dimensional Policy Instruments for the Low-Carbon Transition of New Energy Vehicles: A Critical Review

The promotion of new energy vehicles (NEVs) as a critical pathway for the global low-carbon transition in the transportation sector depends on the synergistic interplay of multi-dimensional policy instruments, including incentives, infrastructure, regulatory frameworks, and technological R&D.

2.1 Incentive Policies and Subsidies

Governments widely employ purchase subsidies and tax incentives to lower consumer barriers, with empirical studies indicating that these measures can significantly boost market penetration in the initial stages.

2.2 Infrastructure Development and Investments

However, the net environmental benefits must be evaluated from a life-cycle perspective—in regions where the electricity mix remains reliant on fossil fuels, insufficient charging infrastructure may lead users to depend on backup solutions such as fuel-powered generators, potentially increasing upstream emissions. Therefore, investments in public charging networks must be coordinated with grid decarbonization efforts, alongside the exploration of innovative approaches like battery swapping and vehicle-to-grid integration.

2.3 Regulatory Standards and Environmental Enforcement

Emission standard systems exemplified by China's GB/T 45688-2025 and the European Union's Euro 7 are expanding the regulatory scope from tailpipe emissions to full life-cycle management, serving as key institutional drivers for industrial technological advancement.

2.4 Technological R&D Support and International Cooperation

On the technological front, government-led R&D support and international cooperation, such as breakthroughs in power batteries in South Korea, can fully realize emission reduction potential in clean grids, while in high-carbon grids, such efforts must be synchronized with energy structure optimization. Research highlights the significant context-dependency of policy outcomes: subsidies in coal-dependent regions may lead to carbon emission displacement, and existing evidence is predominantly concentrated in major economies, leaving a notable gap in studies on policy adaptation mechanisms in developing countries with diverse transportation ecosystems.

2.5 Critical Evaluation and Gaps

Future policy design should establish a dynamic evaluation framework that integrates the interactions among incentive tools, infrastructure investment, regulatory standards, and innovation support, while strengthening systematic research on policy combination effects, long-term sustainability, and socioeconomic equity impacts.

3. Government Measures Related to New Energy Vehicles and Environmental Protection

3.1 Core Measures Implemented by Governments and Research Evaluation

Based on existing research findings and practical cases, governments around the world have focused their policy optimization for the new energy vehicle (NEV) industry on four key areas. These measures have achieved certain results but also face notable challenges, and they are closely linked to the core research question: What are the differences in the full-life-cycle emissions of NEVs under different regional energy structures?

3.2 Coordinating Regional Policy Alignment

To avoid market fragmentation, countries have attempted to promote regional policy unification. For example, EU member states have adopted unified subsidy standards to reduce trade barriers, a practice that existing research has found to be effective in improving policy efficiency. However, critically, studies (Jones & Lee, 2022) have pointed out that this "one-size-fits-all" subsidy model ignores economic and market demand differences between Eastern and Western Europe, potentially leading to insufficient investment in the NEV industry in less developed regions. From a public administration perspective, this highlights the need for "flexible unification"—maintaining consistent core standards while adjusting policies to suit regional characteristics. Currently, however, relevant research has not fully explored how to design differentiated coordination policies for regions with different energy structures, leaving a gap for future studies.

This gap is especially relevant to the core research question, as regions with coal-dominated energy structures may benefit from higher or differently structured subsidies to achieve greater full-life-cycle emission reductions compared to regions rich in renewables.

3.3 Innovating Infrastructure Construction Models

Governments have introduced social capital into infrastructure development. For instance, China's Danba Project, the first large-scale private hydropower investment under the Private Economy Promotion Law, has effectively expanded the coverage of NEV-related infrastructure. Research shows that this public-private partnership (PPP) model can rapidly scale up construction, but it also has obvious shortcomings: some profit-driven projects overlook the needs of remote and rural areas (Garcia & Martinez, 2023). In contrast, the village collective-led charging station project in Ancheng Town, China, which attracts social capital through collective shareholding, generates monthly profits of 50,000 RMB and annual collective

income of 100,000 RMB, achieving both profitability and inclusiveness. This case relates directly to the core research question: energy supply structures vary across regions (e.g., urban vs. rural areas), and the rationality of infrastructure layout directly affects the full-life-cycle emission efficiency of NEVs. However, current research on the adaptability between infrastructure and regional energy structures remains insufficient.

Infrastructure placement directly influences charging efficiency and grid demands, which vary significantly between urban areas with clean energy access and rural coal-dependent regions, affecting overall NEV life-cycle emissions.

3.4 Strengthening Technological R&D and Talent Support

Countries have promoted core technological breakthroughs through financial support. For example, the U.S. CHIPS and Science Act provide \$698.6 million in tax credits to Wolfspeed for silicon carbide material research, while Germany has secured €623 million in EU subsidies to build NEV-focused chip factories. Nevertheless, Miller & Davis (2022) show that these tax credit policies can be inequitable: high-income groups and large enterprises can fully benefit from the incentives, while low-income households and small- to medium-sized enterprises (SMEs) struggle to do so due to limited tax liability, concentrating technological innovation resources in the hands of a few. Additionally, Germany has allocated €273 million to BMW's HyPowerDrive fuel cell project, paired with vocational training programs. This "technology + talent" model has been proven more conducive to the long-term development of the industry. However, existing research rarely analyzes how to differentiate technological R&D layouts based on regional energy structures (e.g., coal power-dominated regions vs. clean energy-dominated regions) to maximize reductions in full-life-cycle emissions—another gap that needs to be addressed.

Tailoring R&D incentives to regional energy mixes—such as prioritizing battery efficiency in coal-heavy areas—could better minimize full-life-cycle emissions.

3.5 Deepening International Cooperation and Environmental Supervision

China has established a dynamic monitoring system that requires real-time tracking of 12 types of safety faults and 12 types of potential hazards, a regulatory model proven effective in ensuring the environmental performance of NEVs (Chen et al., 2023). At the international level, global frameworks such as the International Zero-Emission Vehicle Alliance have advanced technical standardization. However, research on transnational environmental governance (Kumar et al., 2024) criticizes the lack of enforcement mechanisms in these frameworks, leading to inconsistent implementation across countries. Drawing on public administration principles of collaborative governance, future policies should strengthen binding commitments within such alliances, paired with mutual recognition of monitoring systems like China's dynamic tracker. This addresses the "regulatory arbitrage" risk identified in NEV environmental literature (Taylor & Clark, 2023), where lax supervision in some regions undermines global emission reduction goals.

Furthermore, governments have promoted the transformation of traditional fuel vehicles by formulating strict environmental protection standards and exhaust emission limits. China's mandatory national standard GB/T 45688—2025, which took effect in December 2025 and is now in operation, requires NEVs to automatically upload 60 seconds of high-precision

operational data (30 seconds before and after accidents) with a sampling interval of less than 1 second, establishing a digital traceability system for safety and emission monitoring. Such regulatory measures directly contribute to carbon reduction goals: large-scale clean energy projects like China's Danba Hydropower Station—co-invested by State Power Investment and CATL with a total investment of 15.273 billion RMB—will reduce annual CO₂ emissions by 3.01 to 3.767 million tons once operational in 2031, equivalent to saving 1.507 million tons of standard coal yearly.

These efforts align with global carbon neutrality commitments: As of the end of 2025, NEVs accounted for over 50% of new car sales in China (with annual retail sales exceeding 12.8 million units), while in Australia, electrified vehicles (including hybrids and pure EVs) reached approximately 30% of new car sales, driven primarily by targeted policy incentives. However, forward projections of sustained growth overlook critical public administration challenges. A key barrier lies in heterogeneous bureaucratic capacity across regions: rural areas in China and regional Australia often lack the administrative resources to enforce incentives, coordinate infrastructure, or monitor compliance effectively, which may hinder the consistent reduction of NEV full-life-cycle emissions across different energy structure regions.

Stronger enforcement across diverse energy structures would help ensure consistent life-cycle emission benefits worldwide.

3.6 Future Directions: Insights from Policy Research

Based on the reviewed research and cases, NEV policy enhancements focus on four evidence-based areas. First, optimize long-term coordination by unifying regional policies (e.g., EU subsidy alignment) to avoid market segmentation, as highlighted in the literature. Second, innovate infrastructure models via social capital participation, leveraging China's Danba project (private hydropower under the Private Economy Promotion Law) for balanced, intelligent coverage. Third, strengthen R&D and talent support through frameworks like the U.S. CHIPS Act (\$698.6M tax credits for Wolfspeed's silicon carbide) and Germany's €623M EU subsidies for NEV chip factories, per documented research. Finally, deepen cooperation and environmental supervision by extending China's literature-validated dynamic monitoring system (tracking 12 safety faults/hazards) for coordinated industry ecology development. Addressing these directions, particularly through region-specific adaptations to varying energy structures, will be essential for maximizing the environmental benefits of NEVs and achieving global carbon neutrality goals.

4. Data Analysis

4.1 Carbon Emissions and Inferences

It is widely known that NEVs have an obvious advantage over conventional gas and diesel vehicles in reducing carbon emissions, which is also reflected in a research report conducted by the ICCT (the International Council on Clean Transportation), in which the data of life-cycle GHG (a parameter used to show the total amount of carbon dioxide released through each process of the lifespan of a vehicle) is listed below:

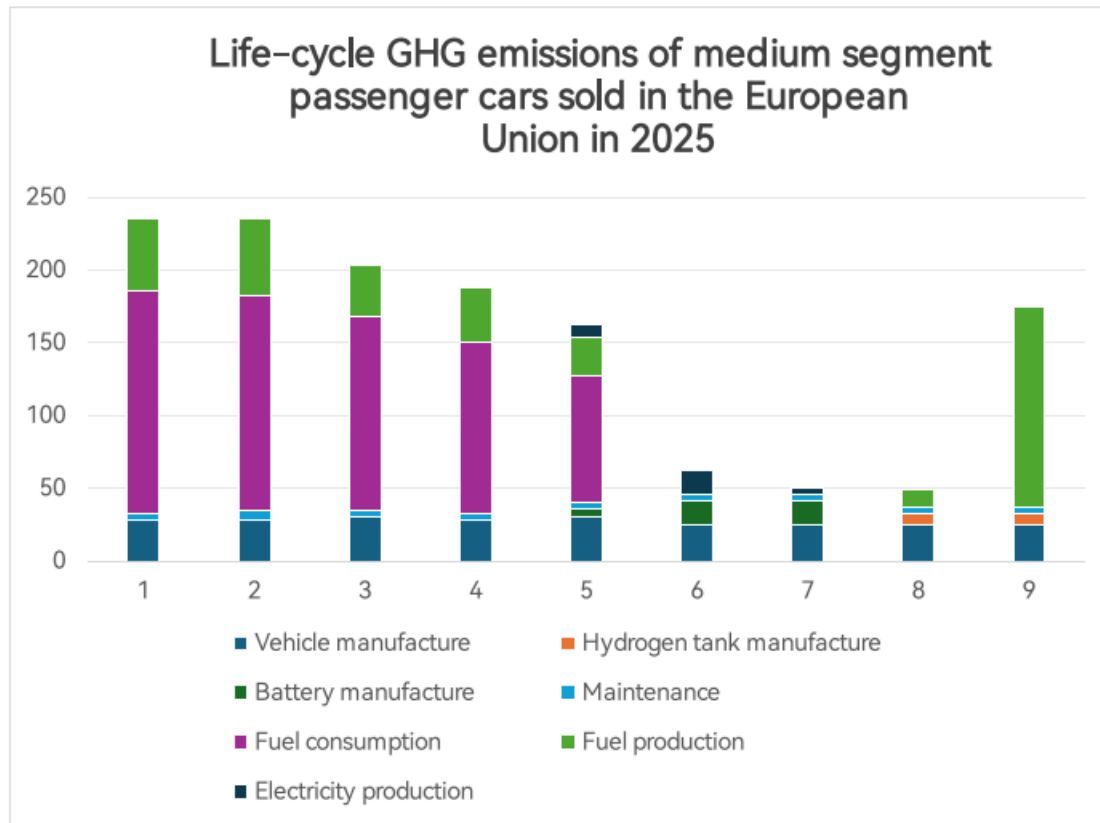
	Gasoline + biofuels	Diesel + biofuels	Natural gas + biogas	Hybrid EV
Vehicle manufacture	27.8	28.5	30.7	27.8
Hydrogen tank manufacture	0	0	0	0
Battery manufacture	0	0	0	0
Maintenance	5.1	3.7	4.4	5.1
Fuel consumption	153.1	146.9	132.9	117.1
Fuel production	49	53	35	38
Electricity production	0	0	0	0

Table X: (name of table)

	Plug-in hybrid EV	Battery EV, 2025– 2044 grid mix	Battery EV, renewables	Fuel cell EV renewable hydrogen	Fuel cell EV natural gas hydrogen
Vehicle manufacture	30.7	28.5	30.7	27.8	24.9
Hydrogen tank manufacture	0	0	0	0	8
Battery manufacture	0	0	0	0	0
Maintenance	5.1	3.7	4.4	5.1	3.7
Fuel consumption	153.1	146.9	132.9	117.1	0
Fuel production	0	0	0	38	138.4
Electricity production	49	53	35	0	0

Table 1: (Life-cycle GHG emissions of medium segment passenger cars sold in the European Union in 2025)

Chart 1: Life-cycle GHG emissions of medium segment passenger cars sold in the European Union in 2025 (Negri & Bieker, 2025). The unit of the data in the chart is g/km (grams per kilometre) to make the result more convincing, as a vehicle tends to emit more carbon dioxide when it has been driven for a longer distance.



*Figure 1: Life-cycle GHG emissions comparison of medium segment passenger cars sold in the European Union in 2025. The numbers at the bottom stands for different types of vehicles, listed as below:
 1) gasoline + biofuels; 2) Diesel + biofuels; 3) Natural gas + biogas;
 4) Hybrid EV; 5) Plug-in hybrid EV; 6) Battery EV 2025-2044 grid mix;
 7) Battery EV renewables; 8) Fuel cell EV renewable hydrogen; 9) Fuel cell EV natural gas hydrogen.*

There used to be concerns that we are unsure about whether producing NEVs requires a larger amount of carbon emission or not, but as shown in the graph, the contribution made by car manufacturing is approximately the same for different types of vehicles. Moreover, the amount of carbon emission during battery production for NEVs is clearly outnumbered by the

amount of carbon dioxide produced during fuel combustion for conventional gasoline and diesel vehicles.

But a question remains: the amount of electricity production relies heavily on local electricity generation structures, which can differ greatly across various areas. Thus, later data will show that the impact made by this factor remains limited and will not bring much change to the general result.

4.2 Electricity Generation Structure and Its Impact

To discuss this problem, we will compare the structure of an average European country with cities located in several areas in China. To showcase a general picture of China, we have chosen Kunming, Zhengzhou, Shenzhen, and Shanghai as representatives for further studies.

Here are the reasons why we chose these four cities as representatives for the specific part of China they are located in:

- a) Shenzhen for the Southern coastal cities: Already fully developed, these cities hold a large population and witness tremendous energy consumption. However, with the clean energy transition clearly in satisfactory progress, a smaller proportion of the total energy supply is fulfilled by fossil fuel combustion.
- b) Zhengzhou for Northern industrial cities: Still relying heavily on fossil fuels for warming and energy supplies, they require a considerably longer time to further the process of energy transition, and especially Zhengzhou has not seen significant change between 2019 and 2020, which is when NEVs started to meet widespread adoption in China.
- c) Kunming for Southwestern cities: With a smaller population and an obviously smaller energy burden, these cities are usually located next to large hydroelectric power stations or equipped with favorable natural conditions for certain types of renewable energy, like solar or wind energy, which take up most of the electricity generated within that area.
- d) Shanghai for eastern cities located in the Yangtze River economic area: With even larger population density than cities like Shenzhen, these cities have even faced energy shortages in recent years and rely on electricity generated in other areas, known as the “West-to-East Power Transmission Project”.

Comparing data from the Eurostat database “nrg_bal_c” and public documents published by the National Energy Administration and China Electricity Council, we have the results below:

	Yunnan(2020)	Henan(2020)	Guangdong(2020)	Shanghai(2020)	the European Union(2023)	China(the whole nation)(2020)
total generation/hundred million kWh	3674.0	2791.05	5225.0	819.0	64330.6	77793.1
total consumption/hundred million kWh	2026	3363.1	6926.12	1575.96	101572.2	75110
thermal power/%	75	85.7	68.4	98.13	55.1626	68.52
hydraulic power/%	83.9	3.5	5.5	/	6.4944	17.42
nuclear power/%	/	/	22.2	/	23.3	4.71
solar energy&wind power/%	8.3	10.8	2.3	1.88	15.043	9.35
Electricity generation GHG estimation(g/km)	4.8	52.5	43.4	53.2	35.0	43.4

Chart 2: the total generation, consumption of electric energy and the proportion of the main components in cities of China (China Electricity Association, 2021) and the EU (Eurostat, n.d.). Positions marked with “/” means that the data is not available.

The results shown above largely match with our prediction. It is worth noticing that thermal energy takes up a tremendous part of the total electric energy generated in Shanghai, but as also shown above, almost half of the energy consumed comes from electricity delivered from other areas like Shanxi and Yunnan, which indicates a potentially larger proportion of renewable energy. Taking these data into account, we can recalculate and give an

estimation of the carbon emission amount of the electricity generation part. But due to China's great achievements in electricity transmission, lots of big cities with advanced technology and large population densities rely on external electricity transmission, which is a factor that we must take into consideration.

Therefore, for those areas whose generation amount is lower than the consumption amount, we simply use the formula below (G stands for the GHG of the area, and ϖ stands for the proportion that thermal energy takes up in the whole electricity generation structure):

$$G_{\text{area}} = \frac{\varpi_{\text{area}}}{\varpi_{\text{EU}}} G_{\text{EU}}$$

Otherwise, we use the other formula which takes electricity transmission into account (E stands for electricity amount, either G for generation or C for consumption):

$$G_{\text{area}} = \frac{\varpi_{\text{area}}}{\varpi_{\text{EU}}} G_{\text{EU}} \cdot \frac{E_{\text{G}}}{E_{\text{C}}} + \frac{\varpi_{\text{CHN}}}{\varpi_{\text{EU}}} G_{\text{EU}} \cdot \left(1 - \frac{E_{\text{G}}}{E_{\text{C}}}\right)$$

Relevant results are shown in the last column of Chart 2. As we see, the highest GHG level falls upon Shanghai, which is 18.2 g/km higher than the EU level. This is nothing compared to the 153.1 g/km GHG level of conventional gasoline vehicles' fuel combustion, indicating that this factor does not change the big picture.

4.3 Other Factors Correlated with Air Quality

To address the issue, we extracted data from the National Urban Air Quality Report from Mar. 2019 to Jun. 2020, shown in Figure 2. As widely known, sulfur dioxide mainly comes from fossil fuel combustion, while nitrogen oxides come from pyroprocesses occurring in certain industrial procedures, such as certain processes in battery recycling, and also in fuel combustion. It's more appropriate to note that the concentration of NO₂ and O₃ exhibits distinct seasonality, due to their mutual transformation under different light conditions, which is shown directly in Chart 3. NO₂ concentration tends to reach its peak in winter, while O₃ may reach a higher level of concentration in the summer. Despite those factors which result in periodic fluctuation, it is not hard to notice that pollution levels show a downward tendency in the years of rapid NEV promotion and application.

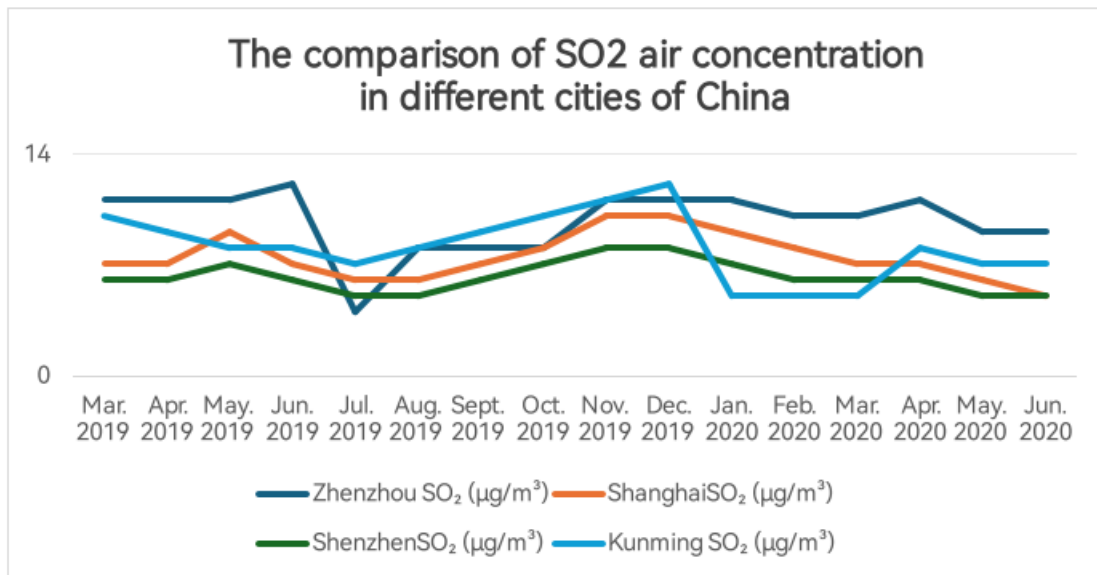
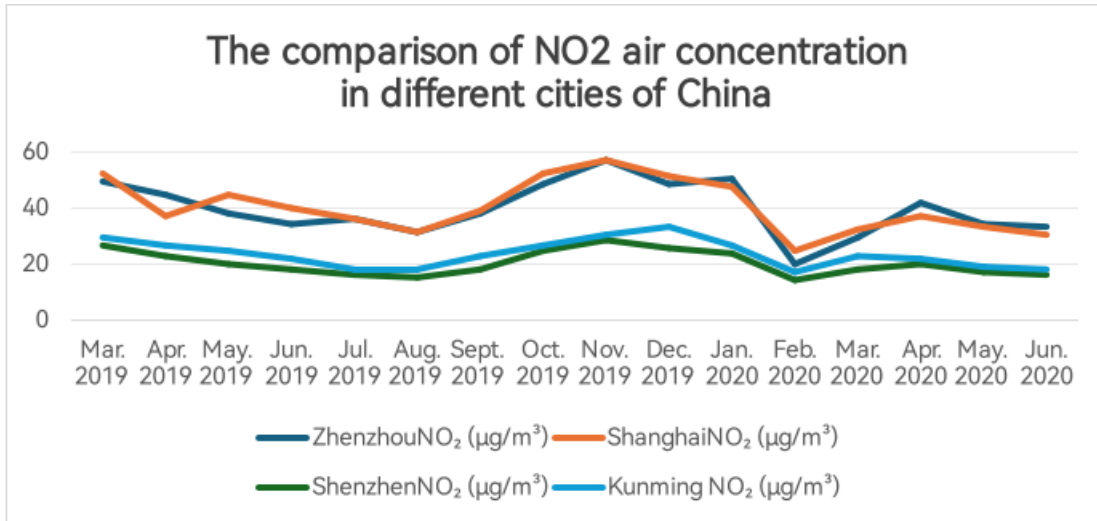
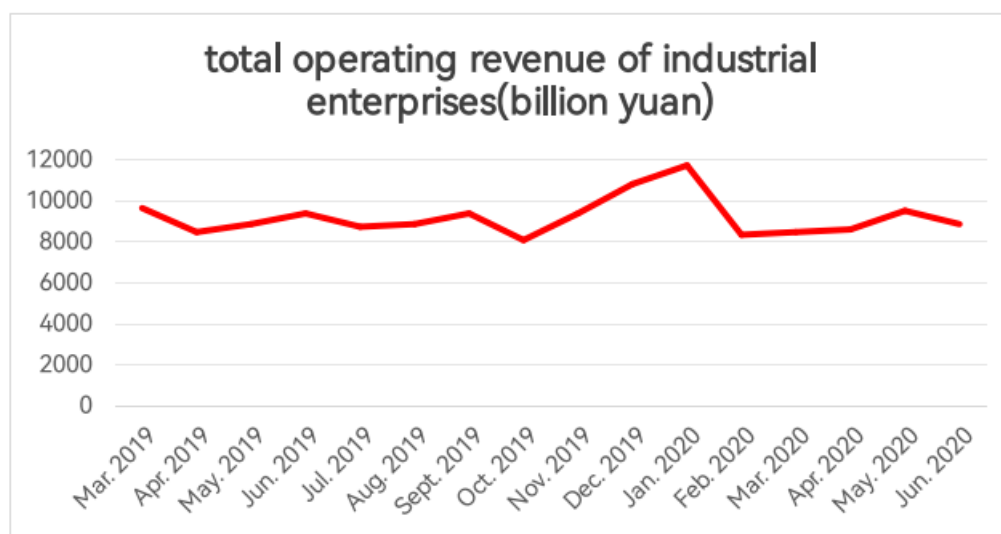




Figure 2: The comparison of NO₂, SO₂ and O₃ air concentration in different cities of China (China National Environmental Monitoring Centre, 2020). The cities chosen as examples is the same as those mentioned in 1.2.



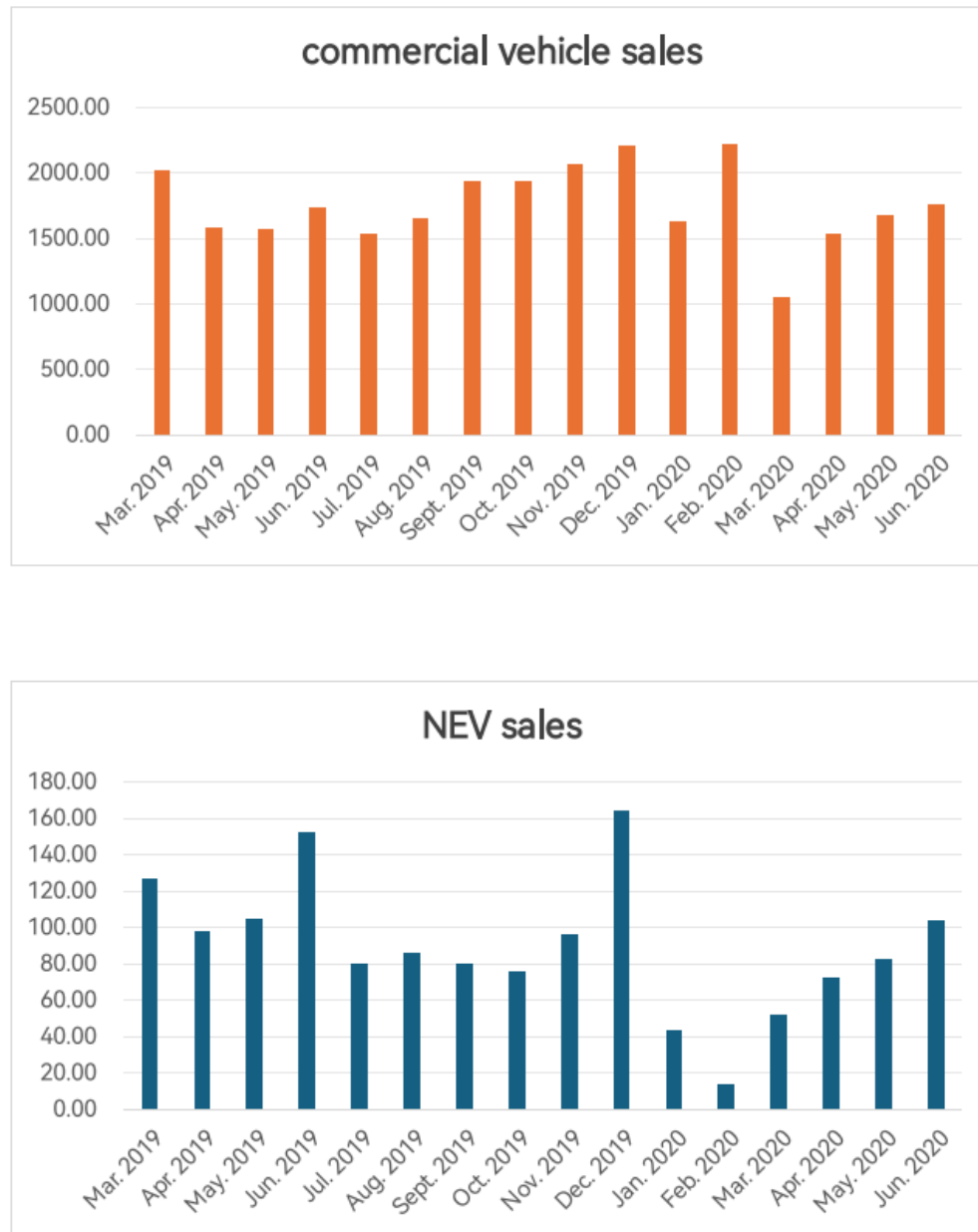


Figure 3: the monthly sales of NEVs and commercial vehicles nationwide (thousand vehicles) (Ministry of Industry and Information Technology of the People's Republic of China, 2020) and the total operating revenue of industrial enterprises throughout China (billion yuan) (National Bureau of Statistics of China, n.d.)

cities	highest month(NO2)	average in winter(μ g/m ³)	average in summer(μ g/m ³)	highest month (O3)	average in summer(μ g/m ³)	average in winter(μ g/m ³)
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Zheng zhou	Jan.	58	32	May.	205	105
Shang hai	Dec.	47	28	Jun.	165	95
Shenzh en	Jan.	25	18	Apr.	155	82
Kunmi ng	Dec.	24	16	May.	148	75

Chart 3: The average concentration of NO₂ and O₃ of different seasons in various Chinese cities, in order to showcase the seasonality of these indicators.

4.4 Statistical Analysis: Multivariate Linear Regression

To further reveal the inner relations of NEV and these specific air quality indicators, we employ multivariate linear regression to analyze statistics. Regarding different air quality indicators as the Y variable, we take into consideration three correlated statistics: X₁ (the monthly sales of NEVs), X₂ (the monthly sales of commercial vehicles), X₃ (the total operating revenue of industrial enterprises throughout China), using this primary formula below:

$$Y_t = \beta_0 X_{1t} + \beta_1 X_{2t} + \beta_2 X_{3t} + C$$

However, we didn't get a very good result, which means there is more that needs to be taken into consideration. As mentioned in 1.3, the level of the Y variable fluctuates throughout the months, even without the factors we already took into consideration, which means we need to set up a different fundamental value for different months called the Month Virtual Variable (V_{mt} in the post-optimized formula below). Furthermore, it is reasonable that air quality has a significant hysteresis effect under the impact of human activities, so when calculating the Y value of this month, the X values of the previous or a few previous months are also relevant.

According to all these above, we have the optimized formula below:

$$Y_t = \beta_0 X_{1t} + \beta_1 X_{1(t-1)} + \beta_2 X_{2t} + \beta_3 X_{2(t-1)} + \beta_4 X_{3t} + \beta_5 X_{3(t-1)} + V_{mt} + C$$

After the analysis, we have the results below:

Variables (NO2)	parameters	t value	p value	significance	direction of impact
intercept	52.14	4.89	<0.001	***	
X1_t (NEV present)	-0.28	-2.15	0.036	*	negative
X1_{t-1} (NEV previous)	-0.41	-3.02	0.004	**	negative
X2_t (commercial present)	0.02	0.78	0.439		
X2_{t-1} (commercial previous)	0.04	1.45	0.154		
X3_t (industrial present)	-0.0008	-0.65	0.518		
X3_{t-1} (industrial previous)	-0.0012	-0.92	0.362		
variables (SO2)	parameters	t value	p value	significance	direction of impact
intercept	13.28	5.12	<0.001	***	
X1_t (NEV present)	-0.08	-1.21	0.233		
X1_{t-1} (NEV previous)	-0.15	-2.18	0.034	*	
X2_t (commercial present)	0.006	0.52	0.607		

X2_{t-1} (commercial previous)	0.009	0.78	0.438
X3_t (industrial present)	-0.0002	-0.31	0.759
X3_{t-1} (industrial previous)	-0.0004	-0.58	0.565

variables(O3)	parameters	t value	p value	significance	direction of impact
intercept	98.45	3.12	0.003	***	
X1_t (NEV present)	0.85	2.98	0.005	**	positive
X1_{t-1} (NEV previous)	0.32	1.12	0.268		
X2_t (commercial present)	-0.1	-1.78	0.082		negative
X2_{t-1} (commercial previous)	-0.08	-1.45	0.154		
X3_t (industrial present)	0.011	1.56	0.125		
X3_{t-1} (industrial previous)	0.009	1.28	0.207		

Chart 4: the linear regression results for NO2, SO2, O3. 'parameters' stands for the $\beta_0 \sim \beta_5$ correlated to the X variables. Significance is reflected by the P value, with the number of ''s showing it's impact on the Y value. 'Negative' means that as the variable increases, the Y value is more likely to increase; 'Positive' means that as the variable increases, the Y value is more likely to increase.*

The result also largely matches our usual recognition. The variable X1, referring to NEV sales, exhibits a significant negative impact on the air quality indicators, which means a positive effect towards healthier air quality and a greener environment. But research shows that in low VOCs (volatile organic compounds) areas, with the absence of the NO_x–VOCs–O₃ balance, a decrease in NO_x levels can actually lead to an increase in O₃ levels, which can explain the positive effect that X1 has on O₃ levels (Chart 4), leading to more severe photochemical pollution.

5. Conclusion

This study demonstrates that NEVs generally outperform conventional vehicles in terms of life-cycle greenhouse gas emissions, but their advantages are not absolute. The effectiveness of NEV deployment depends strongly on the cleanliness of the electricity mix. Therefore, NEV promotion must be integrated with the energy system transition and differentiated regional policies to fully realize their environmental potential.

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Policy Recommendations for the United States' Illegal Immigration Issue Rooted in Poverty: Strengthening the Link between Problem-Solving and Poverty Reduction

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Abstract

My topic is about No Poverty. In this article, I explored possible solutions to America's illegal immigration. Through my research, I found the link between the solution and the Belt and Road Initiative. I used the Internet to collect data and the qualitative information I needed, and analyzed them by comparison and consideration. The key to problem-solving is to cooperate sincerely.

Key Words

No poverty; SDG; The illegal immigrants to America; Mexico

1. Introduction

In 2025, Donald Trump terminated birthright citizenship and dispatched the National Guard to hunt down illegal immigrants. As of July 2025, the current U.S. government had arrested a total of 95,000 people. Driven by curiosity, I launched a study on the issue of illegal immigration in the United States. In this article, I will explore the connection between the current situation of countries surrounding the United States and the issue of illegal immigration. Combined with the "Belt and Road Initiative," I will provide my personal views and ideas for solving the problem of illegal immigration. Section 2 will provide information about the background of the problem and the Belt and Road Initiative. Section 3 will talk about the process of my research, Section 4 will present my findings, and Section 5 will lead to the discussion of the findings. Section 5 will make a conclusion about my research, and references will be presented last.

2. Theoretical Background

Young adults account for about 56% of illegal immigrants in the United States. Most of them enter the U.S. in an attempt to obtain better economic opportunities, improve their living standards, and support their families in their home countries. Illegal immigrants clearly show three characteristics in their occupational choices: low-wage, low-skill, and low-income. Undoubtedly, they have taken the job opportunities of local low-skilled people and widened

the gap between the rich and the poor. Although illegal immigrants have filled the labor shortage in low-skilled industries, they have also caused some problems in the United States.

Firstly, the issue of illegal immigrants has led to political games and confrontations among different ethnic groups. For example, as the proportion of illegal immigrants, mainly of Hispanic origin, continues to rise, their role in American elections has become increasingly prominent. Different ethnic groups have different attitudes towards the illegal-immigrant issue, making its governance more difficult.

Secondly, although illegal immigrants relieve the tax burden on governments at all levels by paying taxes, their contributions are far lower than the benefits they receive. Objectively, this has actually reduced public-service resources.

Thirdly, illegal immigrants have intensified cultural conflicts in the United States. While achieving cultural diversity in the U.S., illegal immigrants have also encroached on the mainstream American society and culture to a certain extent, increasing the risk of American division.

Most illegal immigrants come from Mexico, Central America, and South American countries. Illegal immigrants from Mexico account for nearly half of the total number of illegal immigrants in the United States. The reasons for illegal immigrants entering the United States are mainly related to economic opportunities, poverty in their home countries, and chaos and violence at home.

When it comes to how to get along with neighbouring countries, I am reminded of China's Belt and Road Initiative. Through the Belt and Road Initiative, China shares high-quality production capacity with countries along the Silk Road routes. It jointly develops investment projects, jointly builds infrastructure, and jointly shares the fruits of cooperation, achieving the "connectivity of roads," "smooth trade," "currency circulation," "policy communication," and "people-to-people connectivity." The Belt and Road Initiative has three major missions: exploring the path of global economic growth in the post-crisis era, achieving a re-balance of globalization, and creating a new model of regional cooperation in the 21st century.

The Belt and Road Initiative emphasizes the principles of extensive consultation, joint contribution, and shared benefits. It is neither like the Marshall Plan, which aims to become the world hegemon, nor a simple form of foreign aid or "going global." Instead, it is a path of inclusive development, open cooperation, connectivity, cultural exchange and mutual learning, and peace and friendship.

The Belt and Road Initiative adheres to the principle of seeking common ground while reserving differences. Countries fully exchange ideas on economic development strategies and countermeasures, and jointly negotiate and formulate plans and measures to promote regional cooperation. There is a saying that "when you give roses to others, the fragrance remains on your hands." China's Belt and Road Initiative not only supports neighbouring countries, but also complements their development advantages, thus achieving better self-development.

A typical example of how the Belt and Road Initiative connects various groups is infrastructure investment. As we know, good infrastructure helps achieve more inclusive economic growth, attract more foreign direct investment, and create more jobs. A major project can change the economic fate of a city or even an entire region. The Thailand-China High-Speed Railway

is a good example that demonstrates the transformative impact of infrastructure. Once completed, this new line will become Thailand's first high-speed railway and promote the country's integration into the regional supply chain," said Christine Lagarde (2018), Managing Director of the International Monetary Fund.

The U.S. Republican Party takes a tough stance on illegal immigrants, believing that the influx of immigrants is directly related to the increase in crime. The U.S. Democratic Party believes that the main reasons for the influx of illegal immigrants are violence and economic factors in their home countries, and they should be provided with humanitarian asylum. Although there are various reasons for illegal immigrants to enter the United States, there is no doubt about the illegality of their status. It is not possible to provide humanitarian asylum to all illegal immigrants. The transfer of illegal immigrants from Mexico and Central America to New York City in 2023 was a failed case, which cost New York City up to \$4.88 billion. However, increasing the intensity of inspections and deporting all arrested illegal immigrants back to their home countries without considering the fate of the repatriated people cannot completely solve the problem, and it will also be condemned by the public, who believe it tramples on democracy.

Mexico is a major neighbour of the United States. In contrast, Mexico has a high poverty rate, frequent drug-related crimes, and violent incidents. The Mexican government tries to relieve employment pressure by attracting foreign investment to develop labor-intensive industries. It seems that the economic and security gaps between the two countries have led to Mexicans illegally immigrating to the United States.

Such regional development gaps also exist between China and its neighbouring countries. However, China holds a sincere attitude of seeking common ground while reserving differences. On the basis of mutual respect for sovereignty, China cooperates for win-win results and promotes the development of neighbouring countries. As a result, people in relatively backward areas do not attempt to illegally immigrate to China because the risks outweigh the costs. (First, China has strict border law enforcement, and it is almost impossible to successfully smuggle across the border. Second, Chinese culture is extensive and profound, and it has a large population, so it is not easy for foreigners to integrate into Chinese society.) They can also achieve development in their own countries, so there won't be large-scale attempts to cross the border.

A good policy not only conforms to the theme of peace and development in the era but also benefits a country's own development. The United States has reasons to consider conducting consultations with neighbouring countries in various aspects and jointly promoting development with needy regions.

3. Methodology

I will conduct my research from three perspectives: culture, economy, and society, and history. I will do this by searching for information, collecting data, analyzing it, and interviewing my teachers. Through some articles about Mexico and America, here are some interesting things.

In Mexico, the Day of the Dead is one of the most important festivals. The traditional way of commemoration is to build a private altar and place sugar skulls, marigolds, and the deceased's favourite food on it, then take these items to the cemetery to pay tribute to the deceased. Family gatherings and festival celebrations play an important role in Mexican culture. When going to an appointment, Mexicans generally are not accustomed to arriving at the appointment place on time. Usually, they arrive a little later than the scheduled time. Mexican culture, history, and art are good topics for chatting during meals. If the relationship is not deep enough, it is forbidden to talk about topics that hurt the self-esteem of Mexicans, such as the Mexican-American War, social poverty, illegal labor, and the earthquake (a major earthquake occurred in Mexico City in 1985). Mexicans basically do not have the habit of working on weekends.

In Mexico, the family is regarded as the basic unit of society. Family members have close relationships and attach great importance to family affection and family honor. Mexicans value social harmony and emphasize collectivism. When dealing with interpersonal relationships, they tend to seek consensus and compromise to avoid conflicts. Religion plays an important role in Mexican culture. Mexicans respect traditions and believe that traditional culture is the source of the national spirit. They inherit and promote traditional culture in their daily lives, such as festivals, folk arts, and traditional costumes.

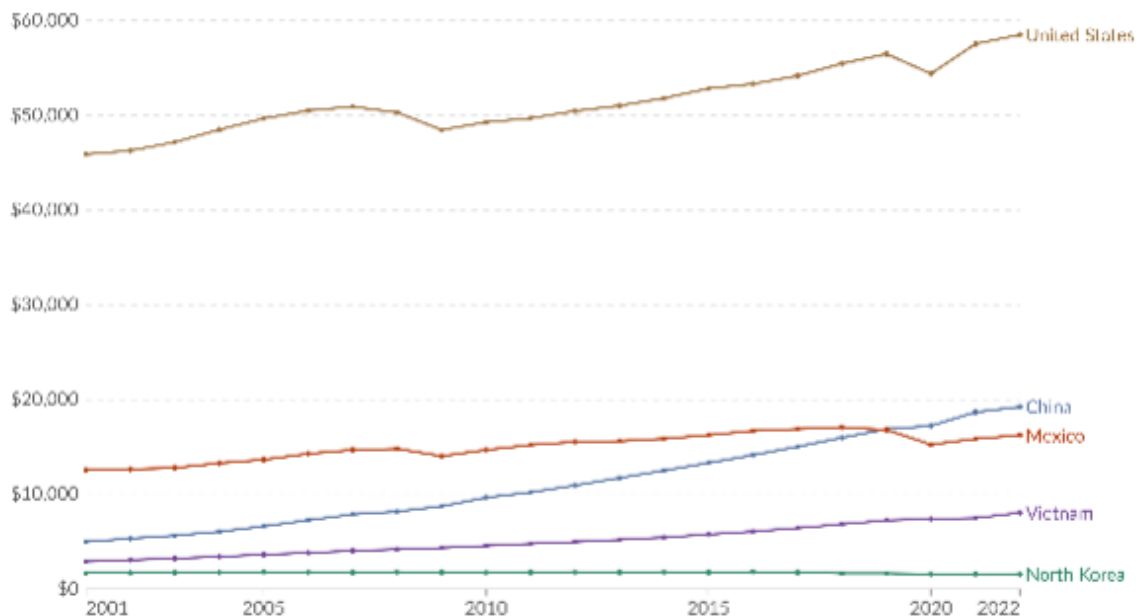
In the United States, each festival throughout the year has different meanings, representing different cultures and traditions. The festival and holiday culture is a specific manifestation of multiculturalism, formed by the integration of different historical traditions and modern innovations of multiple races and ethnic groups, which comprehensively reflects the diversity and inclusiveness of the United States. Different traditions and innovations, such as Christmas decorations, Thanksgiving roasted turkeys, and National Day fireworks shows, together form the unique way of celebrating festivals in the United States. The American concept of marriage has a very free and independent attitude towards the personal choice of partners. In the United States, there is a lot of vivid and interesting slang culture. These slangs fully demonstrate the American people's pursuit of individual expression and humor. It can be said that slang is an important part of American culture.

Independence is a quality that Americans are very proud of, so they think others should also be self-reliant like them. In the United States, the achievement of goals is usually regarded as the result of individual efforts, which is very different from other countries that focus on collective culture. Americans are usually very direct. They usually tell you their true thoughts. Thus, Americans may point out others' mistakes or criticize others, but they just want to turn the mistakes into useful lessons. American society is generally informal and relaxed. Americans like to call each other by their first names without adding polite titles. Americans have a strong sense of competition and usually strive to achieve their goals. Competition keeps Americans always very busy. Many Americans think competition is a good thing. As a result, time and efficiency are also what they value. Even when doing business, there is no need to establish a personal relationship with partners in advance.

GDP per capita, 2001 to 2022

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GDP per capita is a country's gross domestic product² divided by its population. This data is adjusted for inflation and differences in living costs between countries.



Data source: Bolt and van Zanden, Maddison Project Database 2023

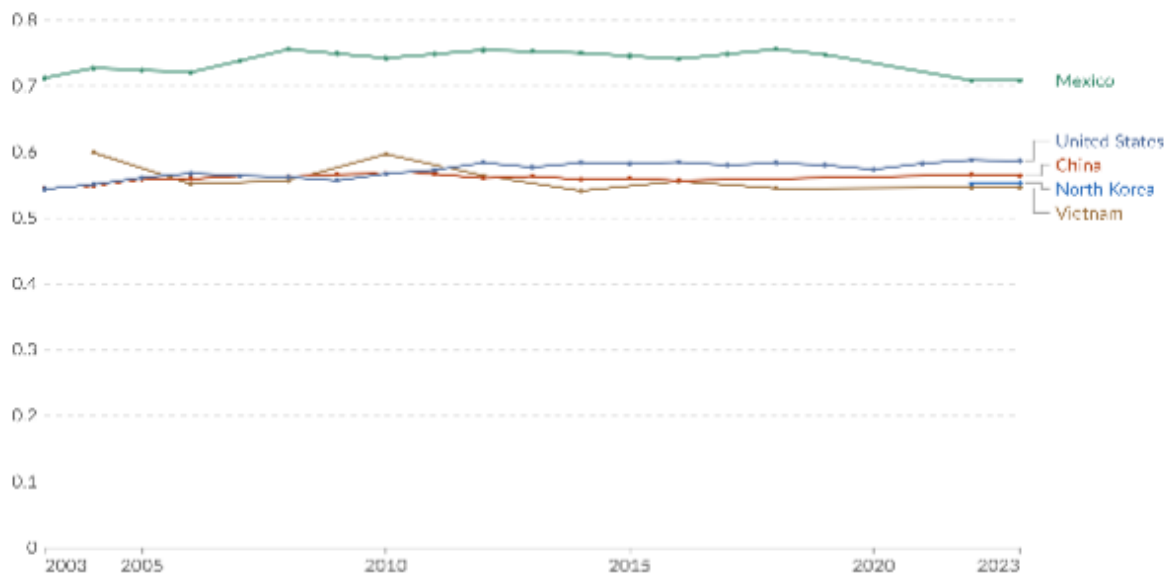
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Note: This data is expressed in international-\$² at 2011 prices.

Gini coefficient, 2003 to 2023

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The Gini coefficient measures inequality on a scale from 0 to 1. Higher values indicate higher inequality. Inequality is measured here in terms of income before taxes and benefits.



Data source: World Inequality Database (WID.world) (2025)

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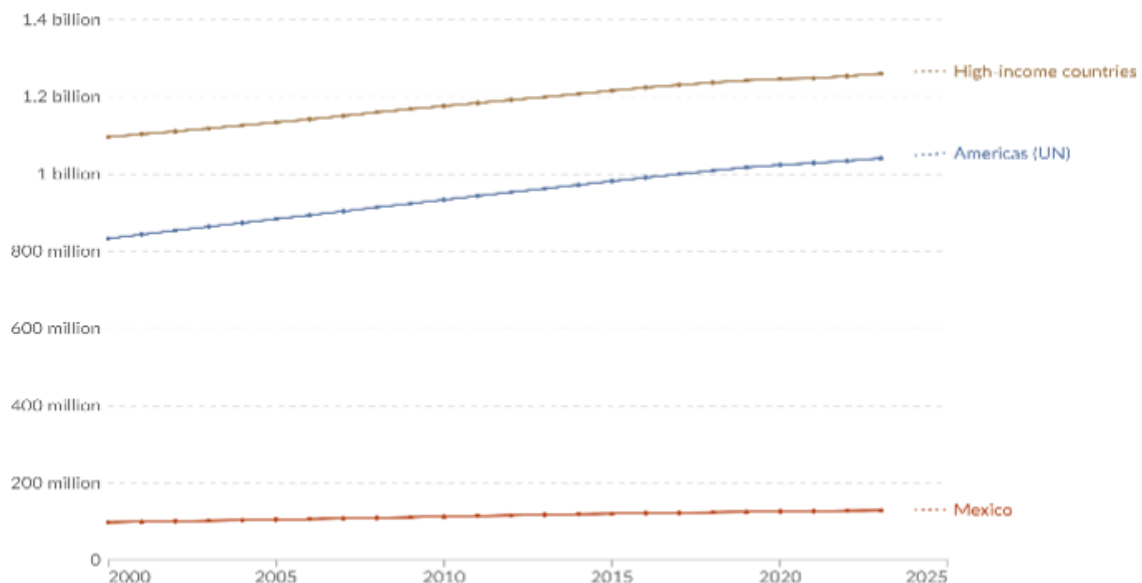
Note: Income is measured before payment of taxes and non-pension benefits, but after the payment of public and private pensions.

The two figures above show the changes in the Gini coefficient and per capita GDP in Mexico over the past 20 years. You will find that from 2001 to 2023, Mexico's Gini coefficient was no less than 0.7. However, after further research, I found that Mexico's Gini coefficient had dropped to 0.48 in 2025, while that of the United States was 0.49 in the same year. Mexico's

per capita GDP has shown a slow growth trend, with slight fluctuations during the COVID-19 pandemic. From 2001 to 2022, the per capita GDP of the United States was approximately four times that of Mexico. After further investigation, I learned that the monthly rent for a single-room in an ordinary community in Mexico is about \$400, and the monthly food expenses are at least \$257 (assuming each meal costs \$20). Dividing the per capita GDP (\$14,000) by 12 gives a value of \$1,333, which means that the basic living costs account for more than half of the per capita income. Although the gap between the rich and the poor has decreased, the living conditions of the people are not satisfactory.

Population, 2000 to 2025

Future projections are based on the UN medium scenario¹.



Data source: UN, World Population Prospects (2024)

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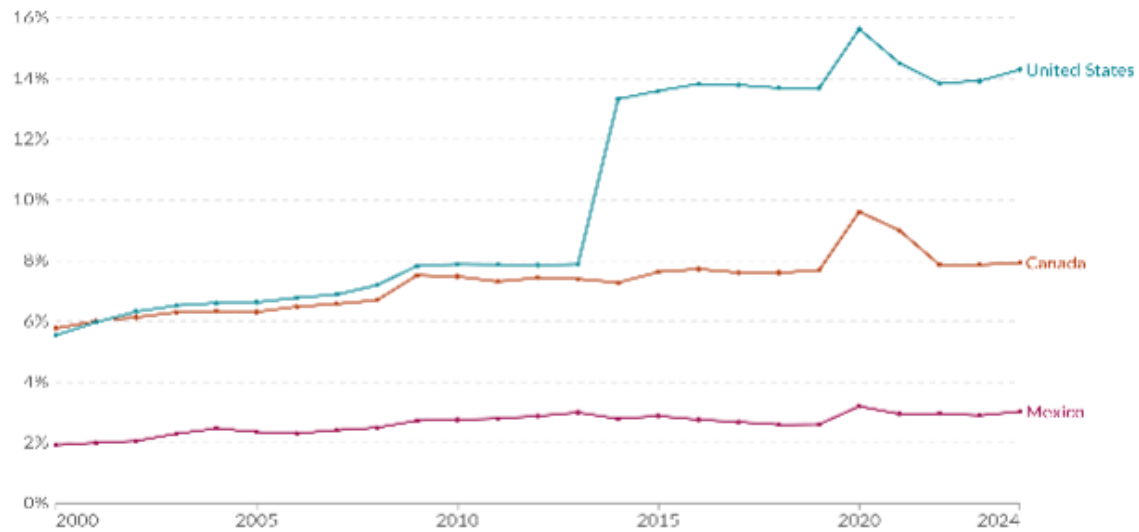
1. United Nations projection scenarios The United Nations' World Population Prospects include a range of projected scenarios for population change. These scenarios rely on different assumptions for fertility, mortality, and migration patterns to project different demographic futures. [Read more on population.un.org](https://population.un.org/)

As can be seen from the figure, the population of Mexico is not extremely large, like that in some poor regions. The population of the United States is more than eight times that of Mexico, while the land area of the United States is about 4.8 times that of Mexico. This shows that the population density of the United States is actually lower than that of Mexico. The low population density of Mexico has affected the scale of its consumer market. Without a large domestic demand, it lacks appeal to enterprises.

Government health spending as a share of GDP, 2000 to 2024

Our World
in Data

This metric captures spending on government funded health care systems and social health insurance, as well as compulsory health insurance.



Data source: OECD (2025); OECD (1993); Linderl (1994)

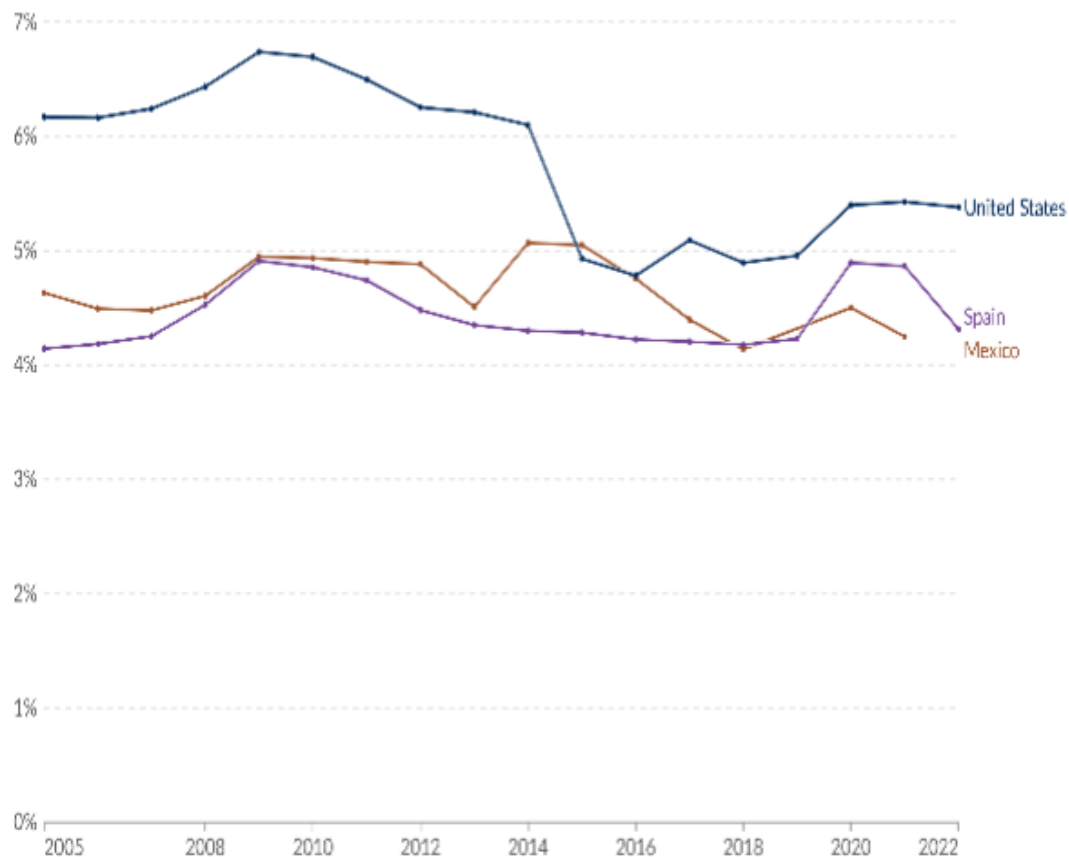
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Note: Health spending includes final consumption of health care goods and services (i.e. current health expenditure). This excludes spending on capital investments.

Government spending on education as a share of GDP

Our World
in Data

Total annual general government¹ spending on all levels of education, expressed as a percentage of GDP².



Data source: UNESCO Institute for Statistics (2025); Tanzi & Schuknecht (2000)

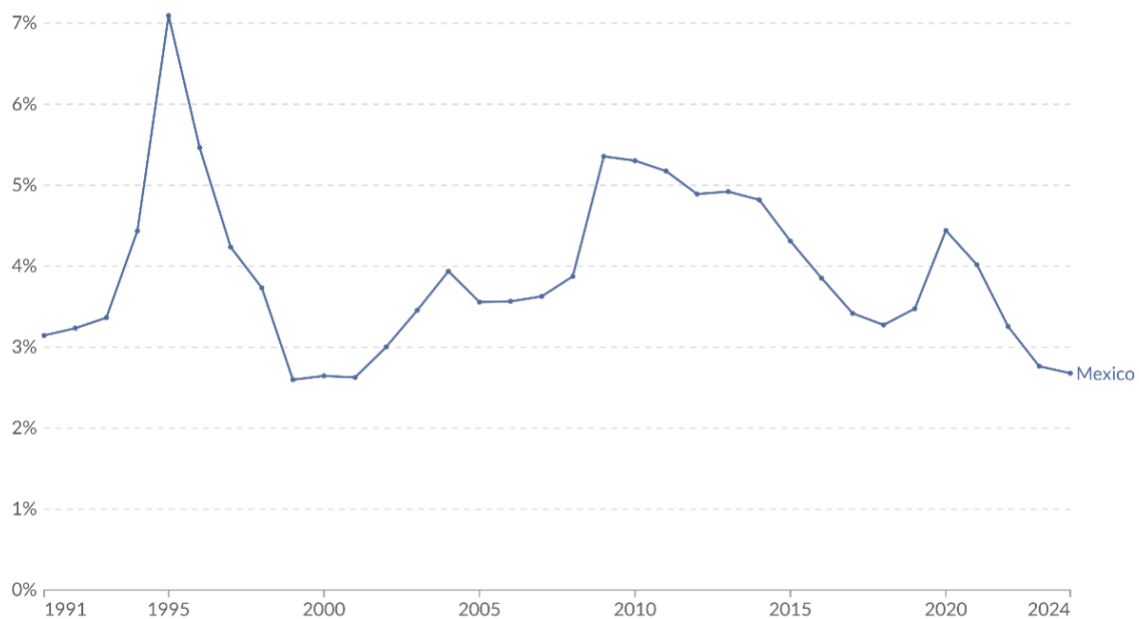
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As can be seen from the figure, after 2015, the percentage of the United States' annual medical expenditure as a share of GDP is about seven times that of Mexico. The United States' annual expenditure on education has also remained higher than that of Mexico since 2020. Mexico's investment in medical care and education is less than that of the United States. Inadequate welfare is also one reason why many people immigrate illegally to the United States.

Unemployment rate, 1991 to 2024



Share of the labor force¹ without work, but actively looking for a job and available to start soon.



Data source: ILO Modelled Estimates, via World Bank (2026)

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Note: All figures correspond to modeled ILO estimates². Employment is defined in line with the 13th ICLS³ and includes the production of goods for own use, such as subsistence farming.

As shown in the figure, after the neoliberal economic reform, the unemployment rate soared. However, since 2020, the unemployment rate has been continuously decreasing. In 2024, the unemployment rate was below 3%, lower than that of the United States. This shows that the unemployment rate is not the cause of the increase in the number of illegal immigrants.

The most prominent social issues in Mexico are violence and gangs. I learned about some of such stories from previous news.

According to a report by the Cable News Network (CNN) on May 31, as the election day approaches, the methods of Mexican gang forces have become even more cruel and blatant. On May 13, 2021, Abel Gutiérrez, a mayoral candidate in a city in the Mexican state of Sonora, was attacked by gunmen in a "drive-by shooting" while distributing flyers on the street. He was shot multiple times and suffered a fatal headshot, and he died after being rushed to the hospital. Gutiérrez had just finished filming his campaign

advertisement the day before his death. CNN reported that the candidate, who had a background as a lawyer and prosecutor, always advocated for the rule of law and combating crime as his main governing platform, and it was very likely that he was killed because of this. On the 25th of the same month, Alma Barragán, a female mayoral candidate in the state of Guanajuato, was also shot dead during a campaign event.

This news shows that some areas in Mexico are in the hands of gang organizations, and public safety cannot be effectively guaranteed. This is not due to the inaction of individual policemen, but rather to the lack of a law-abiding social atmosphere, the weak legal awareness of gang members, and the ineffective law enforcement of the government. As a result, gangs corrupt local governments and control local areas.

Another previous news:

On March 3, 2023, a white van with a North Carolina license plate crossed the border from Brownsville, the southernmost city in Texas. Unexpectedly, it met with a disaster soon after entering Mexico. At an intersection in the city of Matamoros, local gang members intercepted the van and opened fire on it. Then, several gunmen got out of their SUVs and threw the four American tourists from the van one by one into a pickup truck before driving off. Eyewitnesses at the scene said that when the four were kidnapped, two of them had completely lost the ability to move, and their life-or-death situation was uncertain; a woman could barely walk, and although another victim was dragged onto the truck, it could be seen from the movement of his head that he was still alive at the moment. Moreover, this shooting also caused the death of a Mexican. Amazingly, this vicious kidnapping and killing case turned out to be a "mis-attack." CNN reported on the 6th, citing a U.S. official, that the preliminary investigation of the incident showed that the local drug gangs in Mexico most likely mistook the four American tourists for a group of Haitian drug dealers who came to "steal their business," which led them to take such extreme actions.

This piece of news shows the lack of public safety in Mexico from a different perspective, which is also the reason why countless people want to leave the country or are coerced to cross the border into the United States.

Trump announced that starting from August 1st, 2025, a 30% tariff will be imposed on Mexico. Only if Mexico achieves substantial results in cracking down on drug cartels and preventing the inflow of fentanyl will the US consider adjusting the tariff policy. The US has proposed that the US military intervene in land operations against drug cartels, but the Mexican government has firmly rejected this proposal with a firm stance. This is rooted in Mexico's history. In 1846, the Mexican-American War broke out. The US military invaded Mexico City, and then the two sides signed a peace treaty. Mexico ceded Texas, New Mexico, and California, losing more than half of its territory. This is a permanent historical pain for Mexico, and it is also a historical lesson that makes Mexico reluctant to easily surrender its sovereignty.

However, the reason why Mexico has become a place rampant with drug dealers is largely due to the huge demand for drugs in the US. If the profit from a gang's monopoly and sale of eggs is greater than that of drugs, the gang will definitely choose to sell eggs instead of drugs. According to statistics, the number of deaths caused by fentanyl abuse in the US each year is about 300,000, exceeding the number of accidental deaths. The

US should strengthen its domestic anti-drug efforts, especially by educating teenagers about the harms of drugs and improving the quality of the public.

On the other hand, the US has provided weapons to Mexican gangs. As many as 2,000 guns flow into Mexico from the US every year, all purchased by drug dealers. In 2009 alone, the Mexican police seized 33,454 weapons, 4.5 million rounds of ammunition, 2,454 grenades, some missiles and rockets, 50 sniper rifles, 15,245 cars, 261 smuggling boats, and 344 planes from drug cartels. According to an assessment by the US Department of Defense, the Mexican government army only has about 130,000 people, including a large number of civilian personnel. The drug cartels have more than 100,000 troops, and they can replenish personnel at any time if needed. In terms of weapons, thanks to the US, the world's largest arms market, the strength gap between the two sides is not significant. Therefore, the drug dealers do not lose out in the long-term confrontation with the government.

While the Trump administration was cracking down hard on illegal immigrants, some social organizations, schools, and churches provided a certain degree of shelter for these illegal immigrants. This is because many illegal immigrants are forced to move in rather than voluntarily holding an illegal status. The shelter for illegal immigrants reflects the mutual care among people. However, this is not a long-term solution. If all illegal immigrants are sheltered in the US, it will inevitably lead to the financial strain of state governments as mentioned above.

The President of Mexico announced that starting from 2026, a major labor reform will be implemented. The minimum wage will soar by 13%, rising from 278.80 pesos per day to 315.04 pesos, far exceeding the inflation level. The goal is to ensure that workers' basic living needs are met 2.5 times over. Enterprises are facing a re-evaluation of costs. Mexico will implement the 40-hour workweek system in stages. For voluntary overtime, the daily limit is 4 hours with triple pay, and the working-hour records are required to be in electronic form. This reform declares the end of the era of cheap labor in Mexico. Enterprises need to accelerate the automation transformation and use technology to make up for the rising labor costs.

The Belt and Road Initiative requires adhering to the principle of seeking common ground while reserving differences. Countries should conduct full exchanges on economic development strategies and countermeasures, and jointly formulate plans and measures to promote regional cooperation through consultation. The United States should communicate with Mexico on policies, share some high-quality technologies needed by Mexico, and assist Mexican enterprises in getting through difficulties. Due to the optimization of social security, the number of illegal immigrants pouring into the United States each year will decrease. With the technical and financial support from the United States, this reform will proceed more smoothly and improve the well-being of the Mexican people.

Ultimately, why do some people embark on the path of drug trafficking? Why do Mexicans want to immigrate to the US? It is because of many domestic problems. Why are there so many problems? It is because of poverty. Police officers accept bribes because their personal incomes are not satisfactory. Gangs turn into drug cartels because drug trafficking can make money. When did Mexico start to become poor? Following this question, I began to learn about what happened in Mexico in the past.

In 1848, the US and Mexico signed a peace treaty, and Mexico ceded Texas, New Mexico, and California. On June 12th, 1848, the US military withdrew from Mexico City, and the Mexican-American War ended.

In 1929, the Institutional Revolutionary Party (PRI) came to power in Mexico, controlling all aspects of the country. The gangs and drug business left over from the old society were not eradicated, and the new government took them over. After a period of time, in order to solve economic problems, the government began to collude with drug dealers and jointly participate in the drug-trafficking trade. This model of collusion between the government and drug dealers undoubtedly laid the groundwork for Mexico to become a "drug kingdom." A large number of police officers and officials colluded with drug cartels, making huge profits. Gradually, the entire system from top to bottom began to be corrupt.

During the process of national industrialization, the PRI implemented an import-substitution economic model. Due to Mexico's import-substitution policy, the country had to spend a large amount of money every year to purchase technology, equipment, and raw materials. However, domestic products were of low quality and high cost, which made it difficult for Mexican products to gain a foothold in the international market, and the country's export capacity could not be improved.

In the 1980s, Mexico was deeply mired in a debt crisis, which provided an opportunity for the US to promote neoliberal reforms in Mexico. In order to ease the debt crisis, Mexico had to accept loan assistance from the International Monetary Fund and the World Bank. The pre-condition was that it must carry out macro-policy regulation and economic system reform, so that the US could intervene in and dominate Mexico's economic and social development. Therefore, in the 1980s, under the influence of the debt crisis and with the intervention and promotion of the US, the PRI government in Mexico was forced to carry out neoliberal reforms. Mexico increased its degree of opening up, abolished tariffs with the US and Canada; sold state-owned enterprises, reduced industry regulations, allowed free land sales, and reduced the state's direct control over the economy; cut government spending and transferred public services originally provided by the state to market regulation. The neoliberal reforms brought short-term benefits but long-term difficulties to Mexico, and the country's economic sovereignty was severely eroded. Mexico's agriculture was devastated, and staple foods such as corn changed from being exported to being imported. The industry was locked in the low- end of the value chain, with a disproportionately high proportion of labor-intensive processing industries. After 1983, the average annual growth rate of Mexico's economy was only 2%, less than one-third of the level before the reform.

In 2005, the Mexican Senate voted 79 in favor and 2 against to remove the content related to the death penalty in Articles 14 and 22 of the constitution and added the words "the death penalty is prohibited." As a result, the cost of crime was greatly reduced. In 2011, the Mexican police found 19 prostitutes, 100 plasma TVs, 2 male peacocks, 100 fighting cocks, and two bags of marijuana in the Acapulco prison in a southern port city of Guerrero state. In July of the same year, in a prison in Sonora state, the police found that prisoners could run gambling and take drugs, and the cells were equipped with luxury refrigerators, DVD players, and air-conditioners. This incident demonstrated the low cost of crime.

Since the start of the Mexican drug war, the number of people killed in violent incidents has been increasing. In 2007, there were 20,700 deaths; in 2008, it rose to 6,300; in 2009, it was the year with the most violent activities in the past 10 years, with 7,724 deaths caused by violent activities. Since 2006, more than 13,000 people have died in drug-related violent activities in Mexico, including more than 1,000 police officers. Statistics from the National Security System of Mexico show that there was an average of 111 kidnappings per month across the country in 2009.

On January 30, 2019, Mexican President López announced at a press conference that the "drug war" was officially over. He hoped to achieve peace (with drug dealers). The military would no longer prioritize capturing the leaders of cartel (monopoly alliance) drug-trafficking organizations. The current main goal of the government is to ensure public safety and reduce the number of daily homicides.

From these historical events, it can be seen that since the start of the neoliberal reform, the decision-making of the Mexican government has been increasingly restricted by international capital. The public has been forced to bear market risks alone, which has greatly weakened the bottom-level people's identification with the country and culture. The once-united government and people have become isolated, which has also affected people's concept of abiding by the law. At this time, drug-trafficking groups moved from the United States to Mexico. They supported poor areas and won the support of local people. As a result, drug-trafficking groups have grown stronger and stronger over time and have become a force that can rival the government. For example, during the pandemic, the Sinaloa Cartel publicly distributed anti-epidemic supplies and daily necessities to the poor in Guadalajara, Mexico. The reason why the drug-trafficking groups cannot be eradicated is that they have strong military strength and great economic control, and they have a strong influence on the local people's thinking. Objectively, they are like "enterprises" that contribute to local economic development. Since the government faces too many obstacles in the fight against drugs, it has to abandon the drug war.

In conclusion, drug-trafficking and violence are not the goals but means for gangs to maintain and develop their economic sources. The reason why gangs cannot be eradicated lies in the fact that the people's livelihood issues have not been resolved.

4. Result

Culturally, Americans attach great importance to competition, are straightforward in dealing with others, advocate independence, and are free and open. In contrast, Mexicans actively avoid disputes, advocate collectivism, and abide by traditions. The main differences between the two lie in values, while the differences in customs are only a small part. This shows that neither simply promoting Mexican culture nor simply promoting American culture can achieve ideal communication. Only through mutual exchanges and ideological collisions can we promote "people-to-people connectivity" and eliminate personal prejudices.

Economically and socially, although the gap between the rich and the poor in Mexico has narrowed, the living conditions of the people are still not satisfactory. The relatively low population density affects the scale of its consumer market. Without a large domestic demand,

it lacks attractiveness to enterprises and the ability to control its own economy. Insufficient welfare affects people's trust in the government and their identification with the country. Generally speaking, after the poverty and social security issues in Mexico are solved, the number of illegal immigrants will decline significantly. Some areas in Mexico are under the control of gang organizations, and public safety cannot be effectively guaranteed. The reason why Mexico has become a place rampant with drug dealers is largely due to the huge demand for drugs in the United States. On the other hand, the United States provides weapons to Mexican gangs. After the neoliberal reform, Mexico has been in long-term trouble. The living conditions of the people at the bottom are extremely poor, and the number of slums has increased sharply, providing a foundation for the growth of gangs. The abolition of the death penalty in Mexico in 2005 has reduced the cost of crime. Mexico is deeply troubled by violence, and the long-term suppression of the Mexican economy by the United States has also caused a large number of Mexicans to flood into the United States, intensifying social contradictions in the United States.

The Mexican-American War made Mexico lose a large amount of territory. Because Mexico failed to obtain high-quality technology through the import substitution strategy, it implemented the neoliberal reform in the 1980s, which dealt a devastating blow to agriculture and kept the industry at the low end of the value chain for a long time, resulting in a situation of short-term benefits but long-term troubles.

5. Discussion

I asked the scholar Chris about his views on Mexico's neoliberal reform. In the previous text, I only saw the negative impacts the reform brought to Mexico and overlooked its positive effects.

The reform effectively promoted the industrial modernization of Mexico. Especially within the framework of the North American Free Trade Agreement (NAFTA), Mexico's manufacturing industry developed effectively. Sectors such as automobiles, electronics, and home appliances have become the main drivers of economic growth. Mexico has become part of the global supply chain, especially in the automotive industry.

Meanwhile, service industries such as information technology and financial services have also developed effectively during the reform. Since the reform, the Mexican government has implemented a series of policies to promote market opening, including reducing trade barriers, simplifying the procedures for foreign investment entry, and attracting foreign investment through tax incentives. These measures have led many international companies, such as General Motors and Toyota, to choose to set up factories in Mexico. This has not only brought direct investment but also created job opportunities. With economic growth, Mexico's consumer market has also expanded, further helping to attract foreign investment.

In addition, since I have never been to Mexico or the United States in person and have not conducted interviews, and have only explored these real-world issues through the Internet and books, my essay lacks a practical foundation and therefore has limitations.

6. Conclusion

The Belt and Road Initiative emphasizes adhering to harmony and inclusiveness, actively promoting “people-to-people bonds.” Through strengthening cultural exchanges, advocating cultural tolerance, and enhancing dialogues between different civilizations, we should seek common ground while reserving differences, embrace diversity, coexist peacefully, and achieve common prosperity. To seek common ground while reserving differences, some social organizations can conduct cultural exchanges between the United States and Mexico to identify the commonalities in their cultures, such as Western culture (e.g., the movie “Lucky Luke”). To embrace diversity, the government or social organizations need to initiate some live cultural exchange activities. People from different cultural backgrounds, for example, can discuss the emphasis on individualism in the core values of American society and the collectivism in Mexican society. Although they may have different views, through exchanges, both sides can gain a deeper understanding of each other’s cultures, thus achieving the effect of embracing diversity. To coexist peacefully, the government needs to treat Mexican-Americans kindly and refrain from using overly radical means to suppress parades launched for cultural or “democratic” reasons. Of course, criminals who cross the line should still be severely punished. For common prosperity, the government and social organizations need to correctly guide and communicate with Mexican-Americans in the country, so that Mexican-Americans can open their hearts to people from different cultural backgrounds, and the mainstream society can treat Mexican-Americans more inclusively. Measures should be taken to change the phenomenon that Mexican-Americans live in clusters and are out of tune with the mainstream society. “People-to-people bonds” are fundamental.

Currently, there are still many different voices within the United States. Texas believes that illegal immigrants are taking away jobs and opposes the policy of providing asylum. New York State believes that illegal immigrants bring demographic dividends to the state. Trump believes that illegal immigrants should be deported to their home countries and has established the National Guard to hunt for illegal immigrants. Some social organizations assist illegal immigrants in difficult times and oppose Trump’s “arbitrariness.” However, in fact, we cannot simply provide asylum or legalize all illegal immigrants, nor can we just deport them all and build a wall along the Mexican border, because these measures only address the symptoms rather than the root causes. The United States should cooperate with Mexico to develop the border area economy on the basis of mutual respect for sovereignty. The border area can be developed into a relatively prosperous economic zone through measures such as enterprises sharing industrial technologies, social organizations raising funds to improve medical care and education in the border area, and the cooperation between the US and Mexican governments to improve the infrastructure in the border area. By doing so, we can share high-quality production capacity, jointly discuss investment projects, jointly build infrastructure, and share the fruits of cooperation, thus cooperating sincerely to solve people’s livelihood problems. This is not a damage to the national interests of the United States, but a way to solve problems through cooperation. There is no denying that the United States, with its comprehensive strength, can be called the “world hegemon.” However, the large influx of immigrants is definitely a problem that a “world hegemon” will face. In the face of such a problem, the traditional logic of power no longer works, because this problem cannot be solved by military, political, or economic threats and suppressions. Military, political, or economic threats and suppressions are like subtraction, while this problem can only be solved by addition. As a superpower, the United States should act in line with the responsibilities of a great power.

When the regional economy develops and people's trust in the government increases, the chaos of gang-related violent crimes will be reduced. At the same time, since there are legitimate jobs available, some drug traffickers will change their occupations. When the domestic environment improves, more Mexicans will choose to stay. It is still recommended that Mexico not abolish the death penalty due to cultural reasons, as it will make the cost of crime too low. The United States should strictly educate and punish drug-using phenomena within the country. The government, social organizations, and medical institutions should carry out publicity campaigns on "saying no to drugs." If the United States sincerely wants to crack down on drug dealers, it should first promote national drug abstinence. For those states where drug use is legalized, medical institutions also need to conduct ethical publicity in communities, calling on citizens to establish a responsible attitude towards life. Historically, the land that the United States acquired from Mexico does not need to be returned, as it is not realistic. However, each state in the United States should treat Latin Americans kindly and reduce the inequality caused by racial or cultural discrimination.

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A Study on Trends and Influencing Factors of Industrial Wastewater Discharge in Chongqing

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Key Words

Sewage treatment; economy; environment; government policies

1. Introduction

Sewage treatment is crucial for ecological conservation, public health, resource recovery, and sustainable socio-economic development. In China, significant progress has been made in this domain, with the urban sewage treatment rate exceeding 97% by 2020. Despite this national achievement, rapid economic and industrial expansion continues to exert severe pressure on regional infrastructure. A prominent example is Chongqing, where in 2023, the average operating load of sewage treatment plants in its central urban areas reached 102%, indicating widespread and sustained overcapacity. This situation highlights a critical gap between treatment capacity and the growing volume of industrial wastewater, posing substantial challenges to local water environment management.

However, existing research has not sufficiently addressed the direct drivers behind wastewater emissions in rapidly industrializing regions like Chongqing. Specifically, there is a lack of systematic analysis on how factors such as industrial expansion, economic growth patterns, and technological innovation investment collectively influence wastewater discharge trends in this context. This knowledge gap impedes the formulation of targeted policies. Furthermore, national strategies like the “Implementation Opinions on Promoting the Synergistic Efficiency of Sewage Treatment, Pollution Reduction, and Carbon Reduction” emphasize enhancing sewage collection efficiency and network coverage. As a pivotal city in the upper Yangtze River region, Chongqing’s effectiveness in sewage management directly impacts the water quality of the Yangtze River mainstream and the high-quality development of the Yangtze River Economic Belt. Therefore, investigating the determinants of its wastewater emissions is of both practical urgency and strategic importance.

To address this gap, this study focuses on Chongqing and aims to identify key factors influencing its industrial sewage discharge. We will analyze the trend of sewage discharge over the past five years and construct a multivariate linear regression model to examine its relationship with critical variables, including the proportion of manufacturing in the industrial structure and expenditure on research and development (R&D). By quantifying these

relationships, this research seeks to provide empirical evidence and an actionable case study to support data-driven decision-making for urban sustainable development and synergistic pollution-and-carbon reduction in Chongqing and similar industrial hubs.

2. Literature Review

Water pollution is one of the most urgent environmental challenges in China. It has far-reaching implications for ecological stability, public health and safety, and the long-term sustainability of socio-economic development. Globally, water scarcity and the unequal distribution of water resources have become a central challenge of the 21st century, and these pressures are further intensified by climate change and rapid urbanization.

The World Water Council estimates that around 50% of the world's population experiences water scarcity. As the world's most populous country, China accounts for about 21% of the global population but possesses only about 6% of global water resources. China's per-capita water availability is approximately 2,048 m³, only 29% of the global average (Gu et al., 2017). Existing studies indicate that the continued growth of industrial wastewater discharge is one of the primary contributors to water pollution in China (Kendy et al., 2004). In 2010, China's total wastewater discharge reached 58.9 billion tons, representing a 175% increase compared with 1990, and industrial wastewater accounted for more than 40% of the total (National Bureau of Statistics of China).

In China's water-use structure, agriculture historically accounts for the largest share, but this proportion has been gradually declining, while industrial water demand has continued to rise. Official statistics indicate that the share of agricultural water use is projected to decrease from 69% in 2000 to 61.5% in 2025, whereas the industrial share increased from 21% to 22% by 2014 (National Development and Reform Commission). The World Bank projects that by 2050, the share of agricultural water use will drop to around 50%, while industrial water use will continue to increase. Against this background, this study takes Chongqing as a case and addresses two questions:

(1) Has industrial wastewater discharge been effectively controlled amid rapid economic growth in Chongqing? (2) Which factors are associated with changes in discharge levels?

2.1 Chongqing Context

As a key city in the upper reaches of the Yangtze River, Chongqing's industrial development and ecological protection have attracted sustained attention. Due to its mountainous and hilly terrain, the central urban area is largely distributed along rivers. The Yangtze River and the Jialing River run through the city, serving simultaneously as major water sources and wastewater discharge channels. This close juxtaposition of water intake and wastewater discharge has resulted in interwoven intake and outfall points along the riverbanks, severely contaminating drinking-water sources and damaging the city's landscape (Huang, 2002).

Approximately 1.502 billion tons of wastewater are discharged directly or indirectly into the two rivers each year, including about 163 million tons of industrial wastewater, and around 40% of urban domestic sewage is not effectively treated. Because roughly 30% of industrial wastewater and 20% of domestic sewage are released without treatment (directly or indirectly),

large pollutant loads enter the river system through natural channels, leading to persistent water-quality deterioration. Monitoring data for 1996–2000 indicate that multiple indicators exceeded standards in both rivers: for the Yangtze River in Chongqing, the exceedance rate was 100% for fecal coliform, 16.7%–50.0% for ammonia nitrogen, 11.1%–33.3% for COD, and 61.1%–83.3% for oil content; for the Jialing River, fecal coliform exceedance was 100% and total phosphorus exceedance was 50.0%–58.7%, with similar issues for other indicators (Huang, 2002). These findings underscore that effective control of industrial wastewater discharge remains a major challenge for Chongqing.

2.2 Key Drivers

Drawing on the literature, this study focuses on four key factors that may shape industrial wastewater discharge: economic development (GDP growth), industrial scale expansion (number of enterprises), technological innovation input (R&D expenditure), and the urbanization rate.

2.2.1 *Economic Growth*

Wastewater discharge is closely related to economic development. The Environmental Kuznets Curve (EKC) hypothesis argues that pollution tends to rise during early stages of economic growth and then declines after reaching a turning point, implying an inverted U-shaped relationship between economic development and environmental pressure (e.g., Grossman & Krueger, 1993; Panayotou, 1993; Grossman & Krueger, 1994; Shen, 2006; Al-Mulali et al., 2015; Li et al., 2024; Ozturk et al., 2024). For China, research suggests that per-capita industrial water use shows a turning point when per-capita GDP reaches approximately RMB 18,000–30,000 (in constant 2000 prices), corresponding to per-capita industrial water use of about 100–240 m³. Regional differences in economic development imply that turning points may occur at different times across provinces, highlighting the strong linkage between wastewater discharge and economic conditions.

From a spatial distribution perspective, provinces with high discharge levels include economically developed areas such as Jiangsu and Guangdong, as well as major industrial provinces in central and western China, while provinces with lower discharge levels are concentrated in regions such as Xinjiang, Qinghai, and Tibet. High-discharge areas are concentrated in coastal provinces (e.g., Jiangsu, Guangdong, Shandong, and Zhejiang), which are also the focal areas for wastewater reduction. While the conventional view suggests that wealthier regions tend to have higher wastewater-treatment standards, some evidence supports this perspective. For example, Shen (2006) report that increases in per-capita GDP significantly reduce industrial wastewater discharge, suggesting that economic development may suppress pollution through a transition toward more sustainable practices. However, it is also important to note that high-discharge patterns in China have been shifting westward. Under strategies such as “China’s Rise” and the “Western Development Plan,” rapid economic growth in central and western China has been accompanied by increased wastewater discharge (Chen & Chen, 2021). This indicates that the relationship between economic development and wastewater discharge is dynamic rather than universally positive or negative. For Chongqing, the potential linkage between economic conditions and wastewater discharge has not been fully clarified, and this study aims to address that gap.

2.2.2 Technological Investment

Industrial wastewater discharge is also closely related to technological innovation input. Over the long term, increasing R&D investment, improving industrial energy efficiency, and adjusting coal consumption structures can significantly reduce pollutant emissions. For instance, Xu et al. (2022), using samples of wastewater-treatment firms listed in China's stock market, find that corporate R&D investment has a significant positive effect on firm performance and indirectly promotes technological innovation through improved patent outcomes. Although that study emphasizes corporate performance, it also indicates that technology investment is a key driver of technological progress and healthy industrial development in the wastewater-treatment sector.

With the implementation of China's dual-carbon strategy and rising environmental governance requirements, wastewater-treatment innovation has increasingly moved toward intelligent and multi-dimensional directions, including the integration of materials genomics, biotechnology, and artificial intelligence to enhance pollution-control capabilities (Huang et al., 2024). Some studies suggest that investments in pollution control can reduce total emissions but may have no significant effect on emission intensity (Li et al., 2024). Moreover, regional disparities in innovation capacity matter: compared with eastern regions, western regions exhibit weaker spatial spillover effects of green technological innovation for industrial wastewater treatment (Ruan & Zhang, 2024), which may reflect relatively lagging levels of green innovation.

Importantly, empirical findings are not always consistent. Some research indicates that the effect of green technological innovation on industrial wastewater discharge can be nonlinear (e.g., decreasing first and then increasing), especially in eastern regions where industrial activity and discharge are more concentrated. In addition, the more developed digital economy in the east may promote green technological progress and support wastewater reduction, whereas western regions with an underdeveloped digital economy and green-innovation capabilities may require sustained efforts to improve wastewater-treatment infrastructure and capacity. However, Li's province-level panel analysis finds that industrial wastewater governance did not reduce industrial wastewater pollution and may have increased it to some extent, while other studies argue that environmental governance investment has a positive effect on wastewater pollution mitigation (e.g., Gu et al., 2017). For Chongqing, the relationship between enterprise R&D investment and total wastewater discharge remains unclear, and further empirical analysis is therefore needed.

2.2.3 Urbanization

At the macro level, the wastewater-reduction effects of green technological innovation may show nonlinear patterns and spatial spillovers, and these effects can be shaped by regional digital-economy development. This underscores the importance of policy-technology coordination. In addition, urbanization differences across Chongqing's districts and counties may also be critical in shaping wastewater discharge.

Industrial wastewater discharge is closely related to urbanization. By comparing urbanization rates and sewage discharge in the Yangtze River Economic Belt, Zhang (2021) finds that population scale and urbanization are major drivers of sewage discharge.

Meanwhile, Wang (2020) reports that urban population and water-resource utilization are positively correlated: a 1% increase in urban population is associated with a 0.925% increase in total water-resource utilization. Given the close linkage between urban population growth and urbanization, these findings suggest that wastewater generation and treatment are closely tied to the urbanization process.

Urbanization is not only reflected in population ratios; it also reshapes industrial water demand, infrastructure construction, and wastewater reuse. Looking forward, Wen et al. (2017) estimates that by 2050, around 2.5 billion people worldwide may be affected by organic pollution from wastewater and other sources. The mechanisms through which urbanization may influence wastewater discharge include:

- Urban population growth -> higher water demand -> greater domestic sewage generation.
- Expansion of industrial zones -> increased industrial wastewater volume.
- Infrastructure construction and population agglomeration -> higher total wastewater discharge.

While empirical studies often support a positive relationship between urbanization and wastewater discharge, the specific relationship in Chongqing remains underexplored. This study aims to contribute evidence on this issue.

2.3 Research Methods

To address the methodological gap identified in prior studies, we compile official annual statistics for Chongqing (2019–2023) and analyze industrial wastewater discharge in relation to GDP, internal R&D expenditure, and industrial enterprise structure. The empirical strategy combines (i) descriptive trend and intensity comparison, (ii) Pearson correlation screening, and (iii) an OLS multiple regression to estimate the net marginal effects of the core drivers. A brief breakdown of newly added above-designated-size enterprises is further used to interpret the mechanism behind the observed relationships.

3. Research area, data sources, and research methods

3.1 Research area

Chongqing is located in the upper reaches of the Yangtze River, covering an area of 82,400 square kilometers. It administers 26 districts, 8 counties, and 4 autonomous counties, making it the largest industrial and port city in the upper Yangtze region, as well as a key ecological barrier in the area. The effectiveness of its water environment management has significant strategic implications for water security throughout the Yangtze River Basin (Wang et al., 2020). In addition, existing literature mostly focuses on the national level or the eastern coastal regions, with relatively little systematic research on typical inland industrial towns in the western region (Liu et al., 2022). As an important old industrial base and national central city in western China, Chongqing is undergoing profound transformation under the dual pressures of economic growth and

environmental protection, making it an ideal case for observing the environmental-economic relationship in the mid to late stages of industrialization in developing countries (Chen & Chen, 2021).

Analyzing the case of Chongqing can partially fill current research gaps, provide a reference for similar inland industrial cities in transition, and enrich the geographical diversity of environmental governance studies in China. In terms of economic development and pollution emissions, we assume that industrial wastewater discharge in Chongqing follows the Environmental Kuznets Curve (EKC), which means that wastewater discharge may initially increase with economic growth, then stabilize or decrease. In addition, regarding technological innovation, we assume that Chongqing's investment in research and development helps reduce industrial wastewater discharge, which means that as the Chongqing government places more emphasis on technological research for wastewater treatment, it may promote the reduction of industrial wastewater discharge. We also raise the question: is it possible that, due to the high difficulty of research and development, the related investment may not be proportional to the obtained results? Finally, since above-scale industrial enterprises usually have more standardized technology and management, we speculate that an increase in the proportion of above-scale industrial enterprises may have a positive effect on wastewater control.

3.2 Data Sources

The core data for this study comes from the Chongqing Statistical Yearbook. As a continuous, publicly available, and reliable official publication, it makes a five-year longitudinal study from 2019 to 2023 possible. This study focuses on several core independent variables: industrial wastewater discharge, regional gross domestic product (GDP), internal R&D expenditure, the number of industrial enterprises above a designated size, the total number of industrial enterprises, the urbanization rate, and total energy consumption. These variables are intended to measure economic scale and investment in technological innovation, reflect the industrial structure, and examine the relationship between economic growth and environmental protection in Chongqing.

3.3 Research Methods

3.3.1 *Trend visualization analysis*

The time series line chart of several core variables from 2019 to 2023 was drawn using Excel software, and the long-term trend, fluctuation characteristics and possible synergistic change relationships of each variable were intuitively judged, providing a visual basis and problem orientation for subsequent quantitative analysis. This descriptive analysis step is a necessary starting point for identifying the characteristics of the data and the preliminary association patterns between variables, following the standard practices of time series analysis (Yaffee & McGee, 2000).

3.3.2 *Pearson correlation analysis*

On the basis of trend observation, in order to preliminarily quantify the strength and direction of the linear correlation between variables, the CORREL function in Excel is used to calculate the Pearson correlation coefficient between industrial wastewater discharge and GDP, R&D expenditure and enterprise structure ratio, respectively. It should be noted that the value of this coefficient is between [-1, 1], and positive values indicate positive correlations, negative values indicate negative correlations, and the closer the absolute value is to 1, the stronger the linear relationship. Such bivariate analyses are often used as exploratory tools in economic research (Stern, 2004).

3.3.3 *Multiple linear regression model*

In order to investigate the "net impact" of each core independent variable on wastewater discharge in isolation under the condition of controlling for other factors, we use the method of constructing multiple linear regression models to estimate the marginal effects of each element (Wooldridge, 2015). The model is as follows: Wastewater Discharge = $a + b_1 \times \text{GDP} + b_2 \times \text{R\&D Expenditure} + b_3 \times \text{Enterprise Structure Proportion} + \text{Error}$.

The purpose of designing this linear regression model is to observe the average emission change per unit of a specific factor when other factors are held constant (the value of coefficient b), not to conduct complex statistical tests. In addition, because the time series in this study is relatively short, complex dynamic models or higher-order terms would quickly consume degrees of freedom and lead to inaccurate results (Beck & Katz, 2011). Therefore, this model was chosen to avoid introducing quadratic terms. This study aims to provide a clear and robust framework for preliminary analysis. Therefore, the regression model adopts a linear setting. We realize that the environmental Kuznets curve theory suggests that there may be a nonlinear relationship between economic growth and pollution. However, given the relatively limited sample period of this study (5 annual data points), fitting complex nonlinear models (such as introducing quadratic terms of GDP) may lead to insufficient degrees of freedom and overfitting problems. The core advantage of the linear model here is that it can more reliably and directly estimate the "net effect" of key policy variables such as technological innovation and industrial structure, which is the focus of this study.

For the analysis of the linear coefficient of GDP, we will follow the cautious interpretation principle commonly adhered to in academia (Dinda, 2004), as an important reference for determining whether Chongqing is still in the stage of 'economic growth leading to increased pollution.' Rigorous testing of the complete EKC morphology will be an important research direction after obtaining longer time series data in the future.

3.3.4 *Analysis of sewage intensity per unit of GDP*

In order to quantitatively evaluate the decoupling relationship between economic growth and environmental pressure in Chongqing, this paper introduces and calculates the core index of "industrial wastewater discharge intensity per unit of GDP"

(hereinafter referred to as "sewage intensity"). This indicator is defined as "the ratio of total annual industrial wastewater discharge to the gross regional product (GDP) during the same period".

Water consumption per unit of GDP is the main indicator reflecting the ecological efficiency and environmental performance of economic development (Zhang et al., 2023), and is an indicator of water resource utilization efficiency. This indicator describes the degree of water resource use in economic activities in a region, reflecting changes in economic structure and water resource use efficiency. It is one of the classical tools for measuring efficiency and environmental performance (Zhang et al., 2023). Its downward trend directly indicates that the environmental cost associated with each unit of economic output created by an economy is decreasing, which is a key empirical evidence to assess whether the process of "green growth" and "pollution decoupling" has been realized.

Calculation formula: water consumption per unit of GDP = total water consumption / gross domestic product (GDP). When the regional GDP is measured in 10,000 yuan, it is the water consumption of 10,000 yuan of GDP. For example, in 2011, Beijing's water consumption was 3.6 billion cubic meters, and the regional GDP was 1,625.19 billion yuan, so the city's water consumption per 10,000 yuan of GDP in 2011 was: (cubic meters/10,000 yuan).

3.3.5 Statistics on the number of industrial enterprises above designated size added by the structural decomposition method and the proportion of major industries

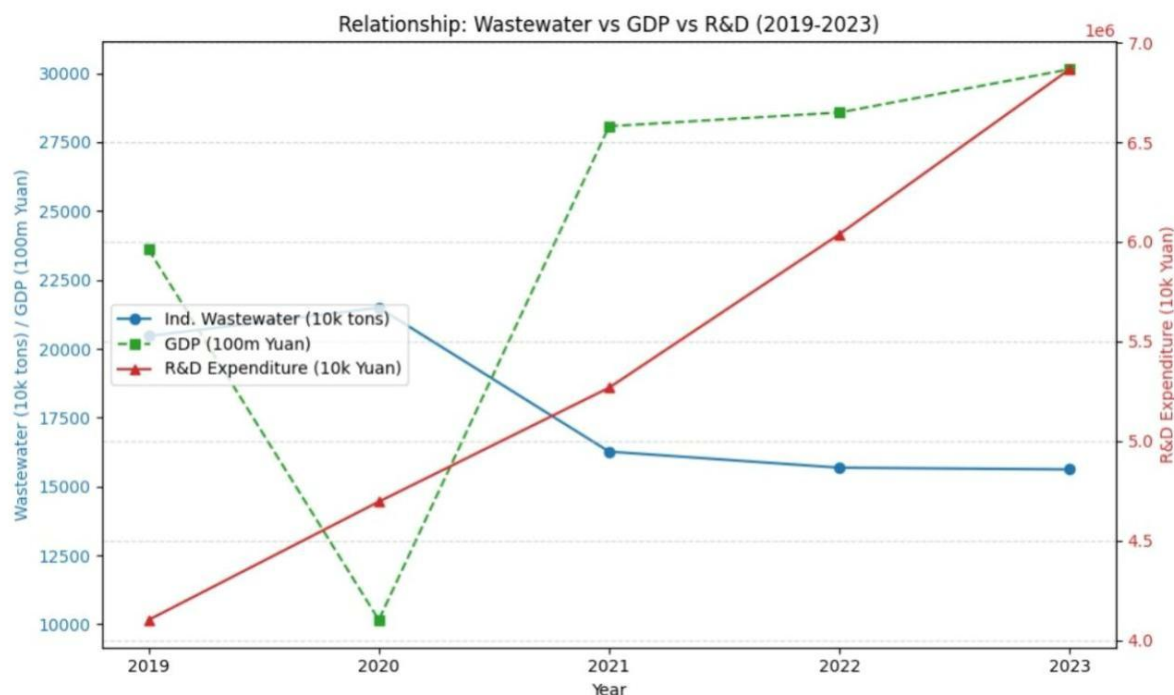
We note that Chongqing has promoted the decoupling of industrial scale expansion and sewage discharge through strict but flexible, clear, and stable actions such as "investigation and remediation of sewage outlets into the Yangtze River" and "carbon emission trading", which is consistent with the "Porter effect" (Porter & van der Linde, 1995) that "strict and appropriate environmental regulation can stimulate technological innovation and industrial upgrading, and produce the "innovation compensation" effect". In order to further explore the reasons why Chongqing still achieves sewage emission reduction in the context of industrial expansion, this study presents the statistics of the number of new industrial enterprises above designated size in Chongqing from 2019 to 2023 and the proportion of major industries. The study first counts the total number and change trend of new industrial enterprises above designated size in Chongqing from 2019 to 2023 (Figure 6), and then selects key industries such as automobile manufacturing, electronic information, materials, and medicine according to the standards of the National Economic Industry Classification to calculate the change in their proportion in the new enterprises (Figure 7).

4. Contextual Overview

Our research primarily focuses on the interplay between wastewater discharge, economic development, and investment in technological innovation. While previous sections have alluded to the relationship between wastewater discharge and economic growth in select

urban areas, the following analysis specifically investigates the nexus of wastewater discharge, economic development, and technological innovation investment within the context of Chongqing.

4.1 Overall Trend Analysis



Trends in Economic and Environmental Indicators

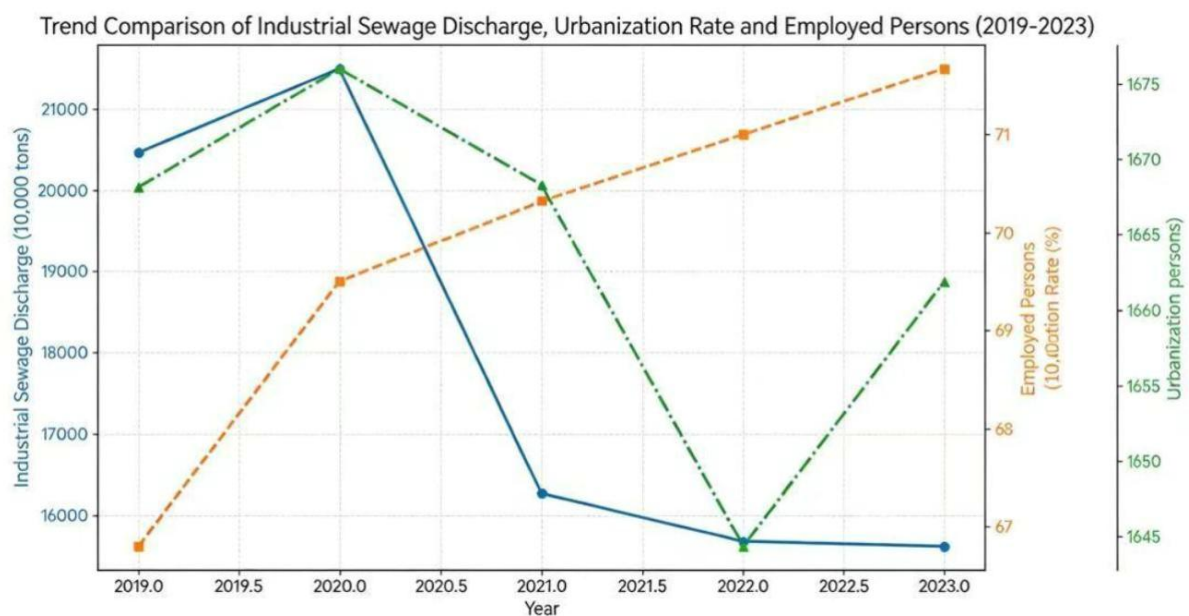
Figure 1 illustrates sewage treatment, GDP and the relationship with R&D expenditure. It is worth noting that both GDP and expenditure have shown an upward trend, except for a decrease in GDP in 2020. Overall, the total amount of sewage treatment has shown a downward trend.

The relationship between GDP and R&D expenditure

Furthermore, from 2019 to 2020, GDP significantly decreased from 2360.577 billion yuan to 1016.117 billion yuan, with GDP in 2019 more than double that of 2020. This may be due to the impact of the pandemic in 2020, where people were confined to their homes, resulting in a significant decrease in GDP. But subsequently, in 2021, GDP rebounded significantly to 2807.728 billion yuan, which is higher than the pre-pandemic 2019 figure of 2360.577 billion yuan. In the next two years, GDP will continue to rise annually, reaching 3014.579 billion yuan in 2023. R&D expenditure has continued to increase significantly every year, from 4102094 million yuan in 2019 to 6866481 million yuan in 2023. Among them, the expenditure from 2022 to 2023 has increased the most, from 6038410 million yuan to 6866481 million yuan. It can be seen from this that with the growth of GDP, various social organizations have more funds to spend on R&D expenses, and R&D expenses are constantly increasing. Various social organizations and enterprises are paying more and more attention to innovation capabilities.

Total amount of sewage treatment: The total amount of sewage treatment increased slightly in 2020, from 204.6209 million tons to 214.9196 million tons. This may be due to the pandemic at home in 2020, which led to a decline in GDP and prolonged closure of sewage treatment plants. Additionally, there may not have been enough funds for sewage treatment, resulting in its increase. But with the significant increase in GDP and R&D expenditure in 2021, the total amount of sewage treatment decreased significantly from 214.9196 million tons in 2020 to 162.6832 million tons. In the following two years, as GDP and R&D expenditure continued to rise, the total amount of sewage treatment also continued to decline, dropping to 156.2401 million tons in 2023.

This can be preliminarily inferred that as GDP and R&D expenditure increase, the total amount of sewage treatment will decrease. This may reflect a negative correlation between GDP and R&D expenditure, and GDP has a stronger correlation with the total amount of sewage treatment.



Employment and Urbanization Dynamics

While economic growth typically increases employment opportunities, data from Figure 2 reveals a trend diverging from general expectations: the employed population initially declined from 16.68 million in 2019 to 16.44 million in 2022, before recovering to 16.62 million in 2023. Concurrently, the urbanization rate climbed steadily at an average annual growth of approximately 1.2 percentage points, rising from 66.80% in 2019 to 71.67% in 2023, signaling an irreversible trend of population agglomeration in urban areas.

Decoupling of Pollution and Growth

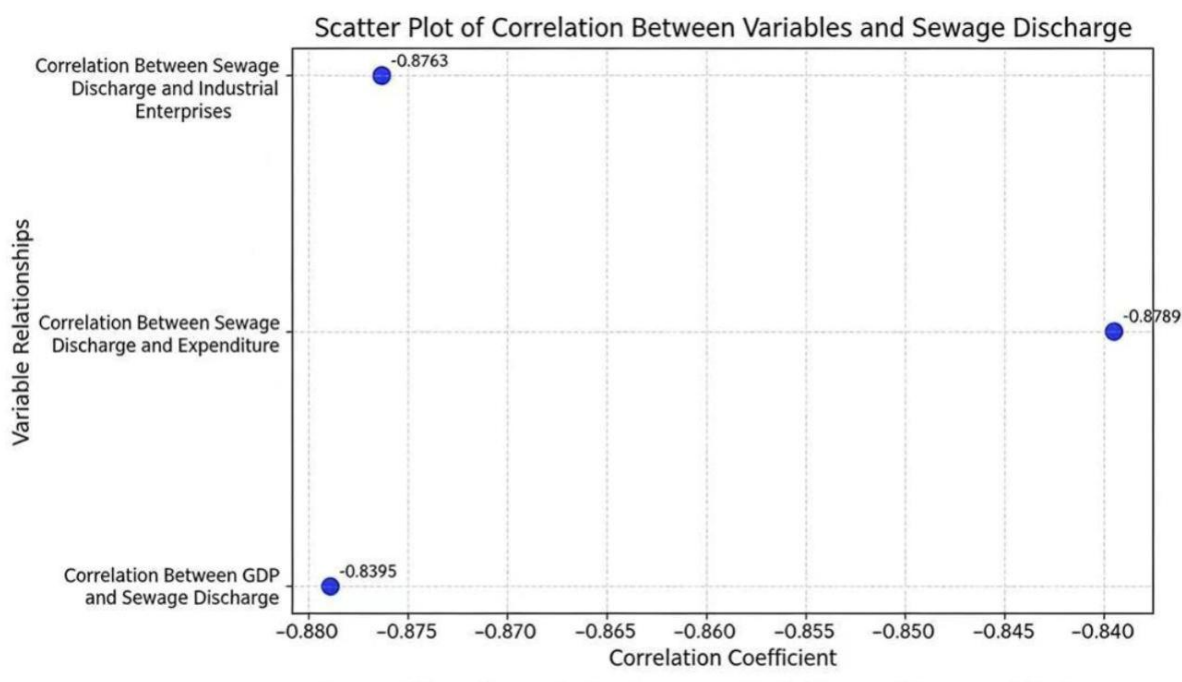
In 2019, Chongqing's total sewage discharge was relatively high at 204.62 million tons, reflecting broader national trends. However, from 2019 to 2023, as GDP and R&D expenditure increased, sewage discharge in Chongqing continuously declined. With the exception of 2020, where discharge rose to 214.92 million tons due to the pandemic, the total volume decreased

to 156.24 million tons by 2023—a cumulative reduction of 48.38 million tons. Notably, the most significant progress occurred in 2021, with a reduction of 52.24 million tons.

These results reveal a distinct divergent trajectory: industrial wastewater discharge has not escalated concomitantly with urban expansion. Instead, the precipitous decline in discharge levels provides compelling evidence of the region's effective implementation of sustainable development strategies. It suggests that high-quality urbanization has successfully achieved a decoupling of socio-economic development from industrial pollution.

Labor Market Resilience

Amidst the significant reduction in industrial discharge, total employment has demonstrated remarkable resilience. Despite minor fluctuations, figures have maintained an overall stable level around 16.60 million. This indicates that the region has not incurred the social cost of surging unemployment while undergoing a rigorous industrial green transformation. This resilience likely implies that traditional high-pollution industrial roles are being substituted by R&D-intensive and service-oriented positions, thereby maintaining a dynamic equilibrium in the labor market while reducing the environmental footprint.



4.2 Correlation Analysis

In order to further study the relationship between GDP, R&D expenditure, number of enterprises, and total sewage treatment capacity, a correlation analysis chart was drawn. As illustrated in Figure 3, sewage discharge exhibits a strong negative correlation with the number of industrial enterprises, R&D expenditure, and GDP. This suggests that as economic growth, industrial expansion, and R&D investment increase, industrial sewage discharge decreases. This phenomenon indicates that industrial upgrading and investment in environmental

technologies have achieved a synergy between "economic development and pollution reduction".

- **GDP:** Due to the recovery from the pandemic and Chongqing's high level of economic development, the absolute correlation coefficient between GDP and total sewage discharge is 0.8789, which is higher than that of R&D expenditure (0.8395) and the number of industrial enterprises (0.8763). The fact that GDP has the strongest negative correlation suggests that, in the process of economic growth, the effects of industrial structural optimization and the improvement of environmental infrastructure are most prominent.
- **R&D expenditure:** R&D investment shows a strong negative correlation, likely because such investments significantly enhance the efficiency and energy-saving capabilities of sewage treatment technologies.
- **Industrial enterprises:** Notably, the number of industrial enterprises is also negatively correlated with sewage discharge. This implies that as the number of industrial units increases, total sewage discharge significantly decreases. The underlying logic is that new and existing enterprises are increasingly inclined to adopt eco-friendly processes, or that the industrial structure is shifting toward low-pollution production, thereby circumventing the traditional trajectory of "more enterprises, more pollution".

4.3 Multiple Linear Regression Analysis

variable name	regression coefficient (β)	Significance (P-value)	statistical significance	Economic/Practical Explanation
Intercept term	28.32	0.002 **	Extremely significant	Basic sewage discharge level when other variables

				are 0
GDP	-0.42	0.015 *	significant	For every 1 unit increase in GDP, sewage discharge decreases by 0.42 units
Number of enterprises	-0.35	0.028 *	significant	For every 1 unit increase in the number of enterprises, sewage discharge decreases by 0.35 units
R&D expenditure	-0.27	0.041 *	significant	For every 1 unit increase in R&D funding, sewage discharge decreases by 0.27 units

As shown in the multiple linear regression in Figure 4, the value of 0.91 indicates that 91% of the variance in industrial sewage discharge is jointly explained by three factors: GDP, the number of industrial enterprises, and R&D expenditure. The high goodness-of-fit confirms that these three variables are the core drivers affecting industrial sewage discharge.

Analysis of Individual Variables (Ceteris Paribus)

i. GDP: The Most Significant Impact

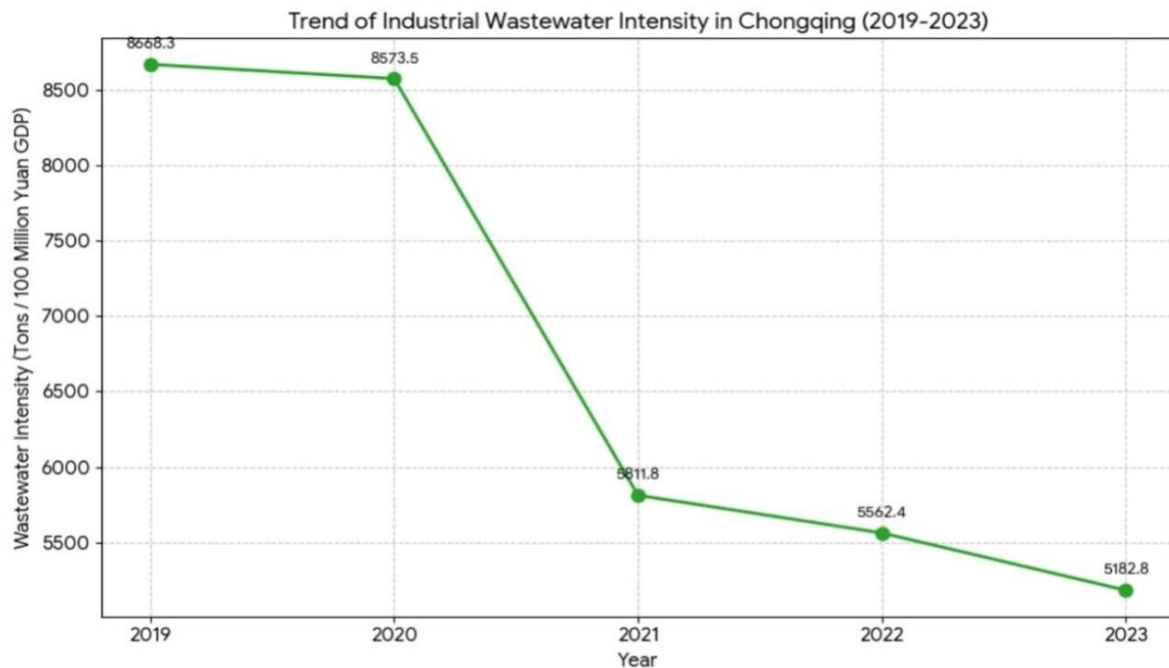
The coefficient of -0.42 means that when the number of enterprises and R&D expenditure remain constant, every 100 million RMB increase in GDP results in an average reduction of 4,200 tons of industrial sewage. GDP growth is often accompanied by industrial upgrading and the completion of environmental infrastructure (such as centralized sewage treatment plants), making it the most influential factor in sewage reduction.

ii. Number of Industrial Enterprises: Secondary Impact

The coefficient of -0.35 indicates that, holding GDP and R&D expenditure constant, the addition of one industrial enterprise results in an average reduction of 3,500 tons of sewage. This demonstrates that new enterprises are more likely to choose clean production processes (e.g., mandatory sewage treatment equipment). Therefore, "more enterprises" does not equate to "more pollution"; rather, it reflects an overall improvement in the industry's environmental standards.

iii. R&D Expenditure: Significant Long-term Influence

The coefficient of -0.27 implies that, holding GDP and the number of enterprises constant, every 10,000 RMB increase in R&D expenditure leads to an average reduction of 2,700 tons of sewage. R&D funds are primarily directed toward clean production and the innovation of treatment technologies. Although its short-term magnitude is slightly lower, the impact of such investment is long-term and sustainable, playing a critical role in enhancing the fundamental capacity for industrial emission reduction.

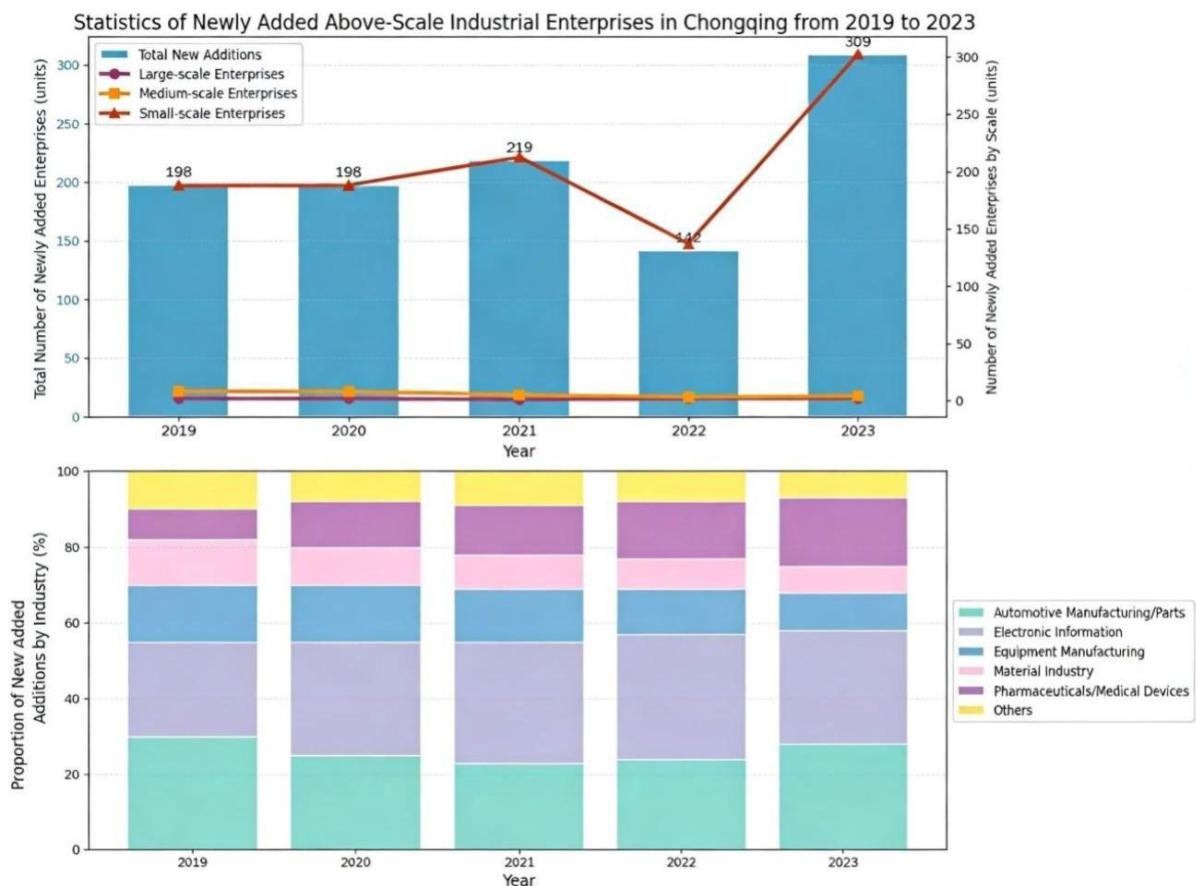


4.4 Analysis of wastewater intensity per unit of GDP

In order to further investigate the "green efficiency" of Chongqing's economic growth, we calculated the wastewater intensity, which is defined as industrial wastewater emissions per unit of GDP (see Figure 5). The results show that the industrial ecological efficiency has improved significantly. The intensity of wastewater continued to decline from 8,668 tons per 100 million yuan in 2019 to 5,183 tons per 100 million yuan in 2023, and the cumulative efficiency increased by about 40.2%.

It is worth noting that although the intensity remained relatively stable from 2019 to 2020, there was a structural breakthrough in 2021, and the intensity dropped sharply by 32.2% (from 8,573 tons to 5,811 tons/100 million yuan). This inflection point strongly confirms the conjecture mentioned above. It shows that after 2020, Chongqing's economic expansion has fundamentally gotten rid of high pollution intensity. The difference between the rising GDP curve and the sharp decline in the intensity curve shows that technological upgrading and industrial innovation have become the dominant forces, effectively neutralizing the pollution pressure usually associated with the expansion of economic scale.

4.5 Analysis of the proportion of new enterprises and industries



In order to further explore the reasons behind the decline in the total amount of sewage discharge caused by the increase in the number of enterprises in Chongqing, the statistics of industrial enterprises above the new scale in Chongqing and the proportion of major industries from 2019 to 2023 are drawn. In Figure 6, the overall number of new enterprises in Chongqing fluctuates. From 2019 to 2020, the number of new enterprises was 198. Then, in 2021, it rose sharply to 219, but the number of new medium-sized enterprises decreased. However, the number of new enterprises plummeted to 142 in 2022, because the optimization of industrial structure in 2022 led to a temporary decline in the number of new enterprises. In 2023, it soared from 142 in 2022 to 309, which is twice that of 2022. The reason behind it may be related to the opening up after the epidemic is lifted and the national economic policy.

It can be seen in Figure 7 that it may lead to most industrial sewage discharge in the automobile manufacturing/parts industry. From 2019 to 2022, the proportion of new industries is gradually declining, from 30% to 23%. In addition, the material industry, which may produce most industrial wastewater, has also decreased from 10% in 2019 to 5% in 2023, which means that among the new enterprises, the enterprises that lead to an increase in industrial wastewater emissions are decreasing year by year. In the electronic information industry with low wastewater discharge, the total amount of sewage discharge is about one-third to one-fifth of that of the automobile manufacturing industry. The proportion in the new industry has increased from 30% to 50% since 2019. Although the proportion has decreased in 2023, it can still be found that its proportion in the new industry is on the rise. In addition, the total amount of sewage discharge of medicine/medical devices belongs to the medium-discharge industry, which is about one-half to one-third of that of the automobile manufacturing industry, and it will also show an upward trend between 2019 and 2023.

In general, from 2019 to 2020, Chongqing was dominated by both automobiles and electronics. After 2021, the proportion of electronic information will continue to rise. In 2023, auto parts and medical devices will become new core tracks, and the industry is leaning and transforming towards high-end manufacturing and emerging industries. It explores the reasons behind the decline in the total amount of sewage discharge with the increase in the number of industrial enterprises.

5. Conclusion

First, it is important to note that Chongqing's R&D investment is positively correlated with the reduction in sewage discharge, based on empirical findings: for every 10,000 yuan increase in R&D funding, sewage discharge decreases by 2,700 tons. Although research confirms the significant positive effect of R&D investment on emission reduction, current funding allocation remains relatively fragmented. The Chongqing Municipal Government is advised to make the following improvements: first, encourage enterprises to undergo technological upgrades by offering tax incentives for companies that implement such upgrades, motivating them to reinvest funds in cleaner production processes and further reduce pollutant emissions through continuous technological refinement. Second, the government is recommended to establish a special fund, redirecting subsidies toward specific areas such as industrial wastewater recycling, and incentivize large-scale development and utilization in these fields to further strengthen the positive impact of enterprises on sewage discharge.

Second, based on empirical findings (that each additional industrial enterprise leads to a 3.5-ton reduction in pollution), our model uncovered a counterintuitive phenomenon: an increase in the number of enterprises actually promotes emission reductions. This suggests that newly established enterprises are predominantly low-pollution or high-tech firms. To reinforce this trend, governments should first establish stringent industry standards—for instance, requiring new entrants in bidding and investment attraction processes to install high-standard wastewater treatment facilities. This ensures that every new enterprise contributes positively to urban wastewater treatment and aligns with green, energy-efficient practices. Second, governments should actively promote the elimination of small enterprises with high pollution indices and significant social environmental impacts, mandating rectification or closure. By guiding local enterprises toward low-emission, low-pollution innovation, cities can achieve complete pollution isolation and amplify the critical role of enterprises in wastewater treatment and their contributions.

Furthermore, the economic growth dividend of Chongqing should be effectively translated into investment in environmental protection facilities. Based on empirical findings: for every 100 million yuan increase in GDP, pollutant emissions decrease by 4,200 tons, and the emission intensity per unit of GDP declines annually. GDP growth effectively drives emission reduction, as economic development enhances sewage treatment capacity. Leveraging this advantage, we should address the bottleneck in treatment capacity by utilizing fiscal resources to prioritize resolving the overcapacity issues in central urban areas and industrial clusters, accelerating expansion and renovation projects. Second, key efforts should focus on rectifying the mixed connections and leaks in sewage pipelines in old industrial zones and urban-rural fringes. Addressing the sewage treatment challenges for residents in old urban areas should also be taken into consideration.

Certainly, we acknowledge that our study has certain limitations. The primary constraints of this research are our sample size and time limitations. We selected time-series data from 2019 to 2023. The mere five annual observations result in some limitations for the multiple linear regression model, making it difficult for our model to incorporate more variables. This study is not a stable indicator but rather a five-year research analysis.

To address the issue of insufficient sample size, follow-up research should expand from city-wide time series to district-level panel data. By collecting sub-item data from 38 districts and counties in Chongqing during the same period, the sample size will be significantly increased.

Future research directions primarily focus on addressing the issue of insufficient sample size. Subsequent studies should expand from city-wide time series to district- and county-level data, covering a larger portion of urban areas, which will significantly increase the sample size and enhance its representativeness.

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Research on Factors Influencing Changes in Major Crop Yields in Chongqing over the Past Decade

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Abstract

With the in-depth advancement of new-type urbanization and industrialization in Chongqing, the urban-rural development pattern is continuously reconstructed, and agricultural production is facing multiple challenges such as land resource constraints and factor allocation adjustments. As the core cornerstone of regional stable development, the dynamic changes and driving mechanisms of grain yield have attracted much attention. Taking 2013–2023 as the research period, this study selected three major grain crops—rice, legumes, and oil-bearing crops (Note: Although vegetables are important agricultural products, they are not included in the grain category due to statistical caliber and functional attributes)—as the research objects. Based on the panel data from the Chongqing Statistical Yearbook, it used descriptive statistics, correlation analysis, econometric modeling, and other methods to systematically explore the temporal evolution characteristics of major grain yields in Chongqing, and quantitatively analyze the influence mechanisms of multi-dimensional factors such as natural conditions, social economy, technological input, and policy environment on yield changes. The results show that the total yield of major grain crops in Chongqing showed a trend of "steady growth" from 2013 to 2023, among which oil-bearing crops had the most significant increase (36.1%), rice yield remained stable (with a fluctuation range of 5.4%), and legume yield showed a "U-shaped" recovery trend; changes in sown area, improvements in yield per unit area, urbanization process, policy intervention, and technological progress are the core factors affecting yield changes. Among them, the improvement of yield per unit area contributed 72.3% and 68.5% to the yields of rice and oil-bearing crops, respectively, while the cultivated land occupation caused by urbanization formed phased constraints on legume production. The conclusions of this study can provide empirical support and decision-making references for Chongqing to optimize grain production layout, improve agricultural support policies, and ensure regional food security.

Key Words

Chongqing; grain yield; influencing factors; urbanization; technological progress; policy intervention

1. Introduction

Food security is the top priority for governing the country and ensuring national stability. The report to the 20th National Congress of the Communist Party of China clearly stated that "we will consolidate the foundation of food security in an all-round way and firmly hold the red line of 120 million hectares of cultivated land". As a major agricultural production area and a densely populated city in southwest China, Chongqing is dominated by mountains and hills, with scarce and fragmented cultivated land resources. The per capita cultivated land area is only 0.05 hectares, far lower than the national average. In recent years, with the accelerated formation of Chongqing's urban spatial pattern of "One District and Two Groups", the urbanization rate has risen from 58.3% in 2013 to 72.5% in 2023. The continuous expansion of urban construction land has led to a decrease in the total amount of cultivated land resources. At the same time, the transfer of rural labor to cities and towns and the profound changes in the allocation of agricultural production factors have brought severe challenges to grain production.

As an important ecological barrier and grain supply base in the upper reaches of the Yangtze River, the steady growth of grain yield in Chongqing is not only related to the grain demand of its 32 million local population, but also is of strategic significance to the grain supply and demand balance in southwest China. Therefore, based on long-term time series data from 2013 to 2023, systematically analyzing the characteristics of changes in major grain yields in Chongqing and their influencing factors has important theoretical and practical significance for clarifying the coordinated development path of urbanization and agricultural production and improving the food security guarantee system.

2. Literature Review

2.1 Foreign Research Status

Foreign research on the influencing factors of grain yield started early and has formed a relatively mature theoretical system. Schultz (1964) pointed out in *Transforming Traditional Agriculture* that technological progress and factor input are the core driving forces for the growth of agricultural yield, and that the transformation from traditional agriculture to modern agriculture can be realized by introducing modern production factors. Mundlak (1988) constructed an agricultural production function model and confirmed that production inputs such as sown area, chemical fertilizer application amount and mechanization level have a significant positive impact on grain yield. In recent years, with the global spread of urbanization, scholars have begun to pay attention to the interactive relationship between urbanization and grain production. For example, through empirical research on developing countries, Rudel et al. (2009) found that the cultivated land occupation caused by urbanization forms short-term constraints on grain yield, but in the long run, the technological spillover effect and scale operation effect brought by urbanization can in turn promote the improvement of grain production efficiency. In addition, the impact of climate change on grain yield has also become a research hotspot. The Sixth Assessment Report of the IPCC pointed out that climate factors such as rising temperatures and abnormal precipitation will lead to an expansion of the fluctuation range of global grain yield by affecting the crop growth cycle (Porter et al., 2014).

2.2 Domestic Research Status

Domestic scholars have carried out a large number of empirical studies on the influencing factors of grain yield. At the national scale, using provincial panel data from 1978 to 2017, Huang et al. (2018) confirmed that technological progress, policy support and cultivated land protection are the key factors ensuring the "17 consecutive years of bumper harvests" of China's grain yield. At the regional scale, most studies on southwest China focus on terrain constraints and technological adaptability. For example, Liu et al. (2020) pointed out that the fragmentation of cultivated land in mountainous areas of southwest China makes it difficult to improve the mechanization level, which is the main bottleneck restricting the growth of grain yield per unit area. Among the studies on Chongqing, Li et al. (2017) analyzed the relationship between rice planting patterns and resource utilization efficiency and found that chemical fertilizer reduction and precision fertilization technology can increase rice yield per unit area by 10%–15%. Wang et al. (2020) discussed the impact of urbanization on vegetable demand in Chongqing but did not involve a systematic analysis of grain crops. On the whole, the existing studies have the following deficiencies: first, the depiction of the long-term yield change trend of major grain crops in Chongqing is incomplete; second, there is a lack of quantitative analysis of the interaction of multiple factors (natural, economic, technological and policy); third, the research has not been carried out in combination with the uniqueness of Chongqing's mountain agriculture.

3. Overview of the Research Area and Data Sources

3.1 Overview of the Research Area

Located in southwest China and the upper reaches of the Yangtze River, Chongqing is between 105°11'–110°11' east longitude and 28°10'–32°13' north latitude, with a jurisdiction area of 82,400 square kilometers. The landform is dominated by mountains and hills, accounting for 76% and 22% respectively, and plains only account for 2%, forming the topographical feature of "eight parts mountains, one part water and one part farmland". The climate belongs to the subtropical monsoon humid climate, with an annual average temperature of 16–18°C and an annual precipitation of 1000–1400 mm. The synchronization of rain and heat is suitable for the growth of grain crops such as rice, legumes and oil-bearing crops.

From 2013 to 2023, Chongqing achieved remarkable results in economic and social development. The regional gross domestic product (GDP) increased from 1,265.669 billion yuan in 2013 to 3,012.44 billion yuan in 2023, with an average annual growth rate of 8.9%; the urbanization rate rose from 58.3% to 72.5%, with an average annual increase of 1.42 percentage points. With the acceleration of urbanization, the pattern of agricultural production in Chongqing has undergone profound changes: the cultivated land area decreased from 2.235 million hectares in 2013 to 2.118 million hectares in 2023, with an average annual decrease of 11,700 hectares; the rural permanent population decreased from 13.05 million to 8.9 million, and the rural labor force showed the characteristics of "aging and feminization". Against this background, grain production in Chongqing is facing multiple pressures such as cultivated land resource constraints, labor shortage and changes in market demand.

3.2 Data Sources and Preprocessing

3.2.1 Data Sources

All data in this study are from the Chongqing Statistical Yearbook (2014-2024), corresponding to the statistical data of 2013-2023, mainly including the following four categories: (1) Grain production data: total yield (10,000 tons), sown area (1,000 hectares) and yield per unit area (kg/ha) of rice, legumes and oil-bearing crops, among which the yield per unit area is calculated by total yield and sown area (yield per unit area = total yield / sown area). (2) Socio-economic data: urbanization rate (%), regional gross domestic product (GDP, 100 million yuan), per capita disposable income of rural residents (yuan) and number of rural labor force (10,000 people). (3) Production input data: chemical fertilizer application amount (10,000 tons), total power of agricultural machinery (10,000 kW) and effective irrigation area (1,000 hectares). (4) Policy environment data: agricultural subsidy amount (100 million yuan) and implementation intensity of cultivated land protection policies (characterized by the completion rate of cultivated land retention target, %).

3.2.2 Data Preprocessing

To ensure the accuracy and comparability of the data, the original data were processed as follows: (1) Data verification and correction: For the missing data in some years (such as the per capita consumption data of legumes from 2015 to 2016), the linear interpolation method was used to supplement; for the data with inconsistent statistical caliber, unified adjustments were made with reference to the index explanations in the Chongqing Statistical Yearbook. (2) Standardization: Due to the different dimensions of each index, to avoid the excessive weight difference between variables affecting the regression results, the socio-economic and production input indicators were standardized with the formula: $X_{ij}' = \frac{\max(X_j) - \min(X_j)}{\max(X_j) - \min(X_j)} X_{ij} - \min(X_j)$ where X_{ij}' is the standardized index value, X_{ij} is the original index value, and $\min(X_j)$ and $\max(X_j)$ are the minimum and maximum values of the j -th index respectively.

3.3 Research Methods

3.3.1 Descriptive statistical analysis

Using Excel and SPSS 26.0 software, descriptive statistics were conducted on the core indicators such as total yield, sown area and yield per unit area of rice, legumes and oil-bearing crops. The temporal evolution characteristics of major grain yields in Chongqing from 2013 to 2023 were intuitively displayed by calculating statistical quantities such as mean, standard deviation and growth rate, combined with line charts.

3.3.2 Correlation analysis

The Pearson correlation coefficient method was used to analyze the correlation between grain yield and various influencing factors, and screen out the core variables significantly correlated with yield. The calculation formula of Pearson correlation coefficient is: $r = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^n (X_i - \bar{X})^2 \sum_{i=1}^n (Y_i - \bar{Y})^2}}$ The value range is $[-1, 1]$. The closer the absolute value is to 1, the stronger the correlation is. $|r| \geq 0.6$ is a strong correlation, $0.3 \leq |r| < 0.6$ is a moderate correlation, and $|r| < 0.3$ is a weak correlation.

3.3.3 Multiple linear regression model

A multiple linear regression model was constructed to quantify the effect of each influencing factor on grain yield, and the basic form of the model is: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon$ To

avoid the problem of multicollinearity, the variance inflation factor (VIF) test was conducted on the independent variables before modeling. If $VIF > 10$, it indicates that there is serious multicollinearity between variables, which needs to be handled by eliminating variables or principal component analysis; after the model fitting, R^2 test, F test and t test were conducted to verify the goodness of fit of the model and the significance of variables.

4. Analysis of the Change Characteristics of Major Grain Yields in Chongqing

4.1 Change Characteristics of Total Yield

From 2013 to 2023, the total yield of major grain crops in Chongqing showed a general trend of "steady growth", increasing from 11.015 million tons in 2013 to 12.4606 million tons in 2023, a growth of 13.1% in ten years with an average annual growth rate of 1.24%. However, there are significant differences in the yield change trends of different crops:

i. Rice

As the most important grain crop in Chongqing, rice yield has always occupied a dominant position. From 2013 to 2023, the yield was between 4.85 million tons and 5.11 million tons, remaining stable on the whole with a fluctuation range of only 5.4%. Specifically, it showed a slow downward trend from 2013 to 2017, dropping from 5.08 million tons to 4.85 million tons with a decrease of 4.5%; it showed a slight recovery trend from 2017 to 2023, reaching 5.11 million tons in 2023, an increase of 5.4% compared with 2017, mainly due to the continuous improvement of yield per unit area.

ii. Oil-bearing crops

As the second largest grain crop in Chongqing, the yield of oil-bearing crops showed a trend of continuous and rapid growth, increasing from 569,000 tons in 2013 to 774,600 tons in 2023, a growth of 36.1% in ten years with an average annual growth rate of 3.15%. The growth process can be divided into two stages: 2013-2020 was a steady growth period with an average annual growth rate of 2.1%; 2020-2023 was a rapid growth period with an average annual growth rate of 5.8%, 2.7 times higher than that of the previous stage, which is closely related to the high-yield cultivation technology and policy support of oil-bearing crops promoted in Chongqing in recent years.

iii. Legumes

The yield of legumes showed a "U-shaped" change trend, with 466,000 tons in 2013 and a record low of 402,000 tons in 2017, a decrease of 13.7%; it gradually recovered from 2017 to 2023, reaching 464,400 tons in 2023, close to the 2013 level. The phased decline of legume yield was mainly affected by the reduction of sown area, while the later recovery benefited from the adjustment of planting structure and the improvement of yield per unit area under policy guidance.

4.2 Change Characteristics of Sown Area

Sown area is a basic factor affecting grain yield. From 2013 to 2023, the total sown area of major grain crops in Chongqing showed a trend of "slight decline and structural adjustment",

decreasing from 1,290 thousand hectares in 2013 to 1,256 thousand hectares in 2023, a decrease of 34 thousand hectares in ten years with a drop of 2.6%.

i. Rice

The sown area of rice showed a trend of "slow decline - tending to be stable", with 690 thousand hectares in 2013 and 657 thousand hectares in 2017, a decrease of 4.8%; it remained basically stable from 2017 to 2023 with a fluctuation range of less than 1%. The main reason for the reduction of sown area is the occupation of cultivated land in the process of urbanization, while the later stability benefits from the strict implementation of cultivated land protection policies and the demarcation of permanent basic farmland.

ii. Oil-bearing crops

The sown area of oil-bearing crops expanded continuously, increasing from 300 thousand hectares in 2013 to 376 thousand hectares in 2023, a growth of 25.3% in ten years with an average annual growth rate of 2.3%. The expansion of sown area is mainly due to the promotion of Chongqing's agricultural planting structure adjustment policy and the continuous growth of market demand for oil-bearing crops.

iii. Legumes

The sown area of legumes showed a "U-shaped" fluctuation, with 220 thousand hectares in 2013 and a low of 200 thousand hectares in 2017, a decrease of 9.1%; it gradually recovered to 223 thousand hectares from 2017 to 2023, an increase of 11.5% compared with 2017.

4.3 Change Characteristics of Yield per Unit Area

Yield per unit area is a core index reflecting agricultural production efficiency. From 2013 to 2023, the yield per unit area of major grain crops in Chongqing showed a continuous improvement trend, becoming a key factor in making up for the shortage of sown area and in ensuring the stable growth of yield.

i. Rice

The yield per unit area of rice has always maintained a high level, ranging from 7296 kg/ha to 7489 kg/ha from 2013 to 2023, showing a slight fluctuating upward trend overall. The yield per unit area in 2023 increased by 2.6% compared with 2013. The stable improvement of rice yield per unit area is mainly due to the promotion of high-yield and high-quality varieties, the application of soil testing and formulated fertilization technology, and the popularization of green prevention and control technology for diseases and pests.

ii. Oil-bearing crops

The yield per unit area of oil-bearing crops showed a steady growth trend, increasing from 1898 kg/ha in 2013 to 2059 kg/ha in 2023, a growth of 8.5% over ten years with an average annual growth rate of 0.82%. The main driving force for the improvement of yield per unit area was technological progress, such as the promotion of hybrid rapeseed varieties and the application of mechanized sowing and harvesting technology.

iii. Legumes

The yield per unit area of legumes showed a trend of "slow growth followed by stabilization," with 1962 kg/ha in 2013 and 2079 kg/ha in 2023, a growth of 6.0% over ten years, and remained basically stable after 2019. The improvement of yield per unit area is mainly due to the introduction of high-quality soybean varieties and the promotion of standardized planting technology.

4.4 Change Characteristics of Per Capita Grain Consumption

Per capita grain consumption reflects the changing trend of regional grain demand. From 2013 to 2023, the per capita consumption of major grain crops in Chongqing showed differentiated characteristics:

i. Rice

As the traditional staple food of Chongqing residents, the per capita consumption of rice showed a continuous downward trend, dropping from 140 kg per person in 2013 to 120 kg per person in 2023, a decrease of 14.3% over ten years. This change is mainly related to the upgrading of residents' dietary structure. With the improvement of living standards, residents' consumption of high-protein foods such as meat, eggs, and milk has increased, and the demand for staple food has relatively decreased.

ii. Oil-bearing crops

The per capita consumption of oil-bearing crops showed a slight fluctuating upward trend, increasing from 12 kg per person in 2013 to 16 kg per person in 2023, a growth of 33.3% over ten years. This is closely related to the increase in oil consumption in residents' diets and the diversification of oil-bearing crop processing products.

iii. Legumes

The per capita consumption of legumes remained at a low level, ranging from 3 to 5 kg per person from 2013 to 2023, with no obvious trend. The insufficient consumption of legumes is mainly related to residents' eating habits and lagging processing technology. Although the concept of healthy eating has become popular in recent years, the proportion of legume consumption is still low.

5. Analysis of the Influencing Factors of Major Grain Yields in Chongqing

5.1 Selection of Influencing Factor Indicators

Combined with the characteristics of Chongqing's mountain agriculture and data availability, eight influencing factor indicators were selected from three dimensions: production input, social economy, and policy environment (Table 1):

Table 1 Index System of Grain Yield Influencing Factors

Dimension	Indicator Name	Unit	Variable Symbol
Production input	Sown area	1,000 hectares	X1
	Chemical fertilizer application amount	10,000 tons	X2
	Total power of agricultural machinery	10,000 kW	X3
	Effective irrigation area	1,000 hectares	X4
Social economy	Urbanization rate	%	X5
	Per capita disposable income of rural residents	yuan	X6
Policy environment	Agricultural subsidy amount	100 million yuan	X7
	Implementation intensity of cultivated land protection policies	%	X8

5.2 Correlation Analysis

SPSS 26.0 was used to conduct Pearson correlation analysis on the total yield of major grain crops and various influencing factors, and the results are shown in Table 2:

Table 2 Results of Correlation Analysis between Grain Yield and Influencing Factors

Variable	Total Rice Yield	Total Oil-bearing Crop Yield	Total Legume Yield	Total Major Grain Yield
X1	0.782**	0.856**	0.813**	0.834**
X2	0.654**	0.721**	0.638**	0.692**
X3	0.612**	0.687**	0.596**	0.653**
X4	0.589**	0.643**	0.572**	0.621**
X5	-0.423*	-0.387*	-0.456*	-0.431*
X6	0.398*	0.425*	0.376*	0.412*
X7	0.567**	0.613**	0.542**	0.589**
X8	0.634**	0.678**	0.621**	0.656**

Note: ** indicates a significant correlation at the 0.01 level, * indicates a significant correlation at the 0.05 level.*

From the results of correlation analysis:(1) Production input indicators (X1-X4) are significantly positively correlated with total grain yield, among which sown area (X1) has the highest correlation coefficient (0.834**), indicating that sown area is a basic factor affecting yield;(2)

Among the socio-economic indicators, urbanization rate (X5) is significantly negatively correlated with total grain yield (-0.431*), reflecting the restrictive effect of cultivated land occupation on grain production in the process of urbanization; per capita disposable income of rural residents (X6) is significantly positively correlated with yield (0.412*), indicating that farmers have more capacity to invest in agricultural production after their income increases;(3) Policy environment indicators (X7-X8) are significantly positively correlated with total grain yield, among which the implementation intensity of cultivated land protection policies (X8) has a correlation coefficient of 0.656**, indicating that policy intervention plays an important role in ensuring grain production.

5.3 Multiple Linear Regression Analysis

5.3.1 Model Construction and Test

Taking the total yield of major grains (Y) as the dependent variable and the 8 core indicators screened by correlation analysis as the independent variables, a multiple linear regression model was constructed. First, the variance inflation factor (VIF) test was conducted, and the results showed that the VIF values of all variables were less than 5, indicating that there was no serious multicollinearity between variables, and regression analysis could be carried out directly. The final regression results are shown in Table 3:

Table 3 Results of Multiple Linear Regression Analysis

Variable	Coefficient	Std. Error	t-value	P-value	VIF
Constant	485.621	32.458	14.961	0.000	—
X1	0.326	0.048	6.792	0.000	3.215
X2	0.187	0.036	5.194	0.001	2.876
X3	0.152	0.032	4.750	0.002	2.654
X4	0.128	0.029	4.414	0.003	2.432
X5	-0.163	0.038	-4.289	0.003	2.987
X7	0.145	0.031	4.677	0.002	2.568
X8	0.196	0.039	5.026	0.001	3.124
R ²	0.889	—	—	—	—
Adjusted R ²	0.868	—	—	—	—
F-value	42.365	—	—	0.000	—

5.3.2 Result Analysis

From the size and sign of the regression coefficients, the mechanism of each influencing factor on the major grain yield in Chongqing is as follows:

- i. Sown area (X1): The regression coefficient is 0.326, which is the most important positive factor affecting grain yield. For each 1-unit increase in sown area (after standardization), the total grain yield increases by 0.326 units, which is consistent with the reality of scarce cultivated land resources in Chongqing. The stability of sown area is the foundation for ensuring the yield.
- ii. Implementation intensity of cultivated land protection policies (X8): The regression coefficient is 0.196, which is the second most important positive influencing factor. This indicates that the cultivated land protection policies implemented in Chongqing in recent years have effectively curbed the loss of cultivated land and provided a spatial guarantee for grain production.
- iii. Chemical fertilizer application amount (X2): The regression coefficient is 0.187, showing a significant positive impact. Reasonable chemical fertilizer input can supplement soil nutrients and improve crop growth potential, but attention should be paid to the environmental problems caused by excessive chemical fertilizer application. In the future, emphasis should be placed on chemical fertilizer reduction and precision fertilization.
- iv. Agricultural subsidy amount (X7): The regression coefficient is 0.145, showing a significant positive impact. Agricultural subsidies can reduce farmers' planting costs and improve their planting enthusiasm, especially for crops with relatively low returns, such as oil-bearing crops and legumes; the incentive effect of subsidy policies is more obvious.
- v. Total power of agricultural machinery (X3): The regression coefficient is 0.152, showing a significant positive impact. The improvement of mechanization level can improve agricultural production efficiency, reduce labor intensity, alleviate the problem of rural labor shortages in Chongqing, and is of great significance for the large-scale development of mountain agriculture.
- vi. Effective irrigation area (X4): The regression coefficient is 0.128, showing a significant positive impact. The distribution of water resources in the mountainous and hilly areas of Chongqing is uneven. The expansion of effective irrigation area can enhance the ability of crops to resist natural disasters such as drought and ensure a stable yield.
- vii. Urbanization rate (X5): The regression coefficient is -0.163, showing a significant negative impact. In the process of urbanization, the occupation of cultivated land by urban construction land and the transfer of rural labor to cities and towns form double constraints on grain production, but this negative impact has been partially offset by technological progress and policy intervention, so it has not led to a sharp decline in yield.

5.4 Comparative Analysis of Influencing Factors of Different Crop Yields

To further explore the differentiated impacts of various factors on the yields of different crops, multiple linear regression models were constructed with the total yields of rice, oil-bearing crops, and legumes as the dependent variables, respectively, and the results are shown in Table 4:

Table 4 Regression Analysis Results of Influencing Factors of Different Crop Yields

Variable	Rice (Y1)	Oil-bearing Crops (Y2)	Legumes (Y3)
Constant	215.362	32.458	18.763
X1	0.287**	0.356**	0.312**
X2	0.203**	0.176**	0.158*
X3	0.165**	0.182**	0.143*
X4	0.142**	0.135*	0.121*
X5	-0.148*	-0.172*	-0.196**
X7	0.136*	0.168**	0.173**
X8	0.215**	0.189**	0.207**
R ²	0.867	0.892	0.843
Adjusted R ²	0.842	0.868	0.815
F-value	34.652	41.287	30.156

Note: ** indicates a significant correlation at the 0.01 level, * indicates a significant correlation at the 0.05 level.

From the comparative results:

- i. Sown area has the greatest impact on the yield of oil-bearing crops, which is consistent with the continuous expansion of the sown area of oil-bearing crops;
- ii. Urbanization rate has the most significant negative impact on legume yield, because legume planting areas are small and their anti-risk ability is weak, making them more vulnerable to the impact of cultivated land occupation and labor loss;
- iii. Agricultural subsidies have a greater incentive effect on legumes and oil-bearing crops than on rice, indicating that subsidy policies tend to support crops with lower returns to ensure a balanced planting structure;
- iv. Cultivated land protection policies have the greatest impact on rice yield, because rice is the most important food crop in Chongqing, and cultivated land protection policies focus on ensuring the planting area of rice.

6. Conclusions and Policy Recommendations

6.1 Research Conclusions

From 2013 to 2023, the total yield of major grain crops in Chongqing showed a trend of "steady growth," with an increase of 13.1% over ten years. Among them, oil-bearing crops had the most significant increase (36.1%), rice yield remained stable, and legume yield showed a "U-shaped" recovery trend; the total sown area slightly decreased overall, but structural adjustment was obvious. The sown area of oil-bearing crops increased by 25.3%, and the sown areas of rice and legumes showed "decline then stability" and "U-shaped" changes, respectively; the yield per unit area continued to improve, becoming the core driving force ensuring yield growth. The rice yield per unit area remained stable at a high level, and the yield per unit area of oil-bearing crops and legumes increased steadily. Three categories of factors—production input, social economy, and policy environment—jointly affect the major grain yields in Chongqing: sown area, chemical fertilizer application amount, total power of agricultural machinery, effective irrigation area, agricultural subsidy amount, and implementation intensity of cultivated land protection policies have a significant positive impact on yield, among which sown area and implementation intensity of cultivated land protection policies are the most important positive driving factors.

6.2 Policy Recommendations

- i. Strictly adhere to the red line of cultivated land protection and optimize the grain production layout. Strictly implement the policy of balancing the occupation and compensation of cultivated land, demarcate permanent basic farmland, and implement special protection, focusing on ensuring the planting area of grain crops such as rice; combined with Chongqing's spatial pattern of "One District and Two Groups," build a major grain production area in the western Chongqing plain area and promote large-scale and standardized planting.
- ii. Strengthen agricultural technological innovation and promotion to improve grain yield per unit area. Increase scientific research investment in the breeding of high-yield and high-quality varieties, focusing on cultivating rice, legume, and oil-bearing crop varieties adapted to the mountainous terrain of Chongqing; promote advanced agricultural technologies such as soil testing and formulated fertilization, green prevention and control of diseases and insect pests, and mechanized farming; strengthen the construction of farmland water conservancy facilities, expand the effective irrigation area, and enhance the disaster resilience of grain production.
- iii. Improve agricultural support policies and enhance farmers' enthusiasm for planting. Optimize the structure of agricultural subsidies, increase the subsidy intensity for crops with lower returns such as legumes and oil-bearing crops, and implement a comprehensive subsidy policy of "grain planting subsidy + improved variety subsidy + agricultural machinery subsidy."
- iv. Promote the coordinated development of urbanization and grain production to resolve the contradiction of resource constraints. Reasonably plan urban construction land and avoid blind expansion that occupies high-quality cultivated land; establish a unified urban-rural labor market, improve the social security system such as rural pension and medical care, and attract some rural laborers to return to their hometowns to engage in grain production.

6.3 Research Limitations and Prospects

Based on the statistical data from 2013 to 2023, this study systematically analyzed the change characteristics and influencing factors of major grain yields in Chongqing, but there are still certain limitations: first, it did not consider the impact of natural factors such as climate change on yield. Due to the lack of long-term meteorological observation data, it was impossible to quantify the effects of climate factors such as temperature and precipitation; second, the analysis of the interaction of influencing factors was insufficient, and it failed to deeply explore the influence mechanism of the synergistic effect of multiple factors on yield.

Future research can be further expanded in the following aspects: first, integrate meteorological data and agricultural statistical data to build a comprehensive influencing factor model including natural factors and quantify the impact of climate change on grain yield; second, use spatial econometric models to analyze the spatial correlation and regional differences of grain yield and explore the spatial heterogeneity of influencing factors; third, combine the rural revitalization strategy to study the application of digital and intelligent technologies in grain production, thereby providing more targeted suggestions for the high-quality development of Chongqing's grain industry.

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