Journal of Sustainable Management and Social Progress

https://jsmsp.cultechpub.com/jsmsp

E-ISSN: 3120-337X

Vol. 2, No. 1, May 2026

DOI: 10.64229/pjaade58

Article

Industrial Path Dependence and Water Resource Externality: A Comparative Study of Tuhua Village and Xiaozhou Village in Guangzhou, China

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Abstract

This study examines how industrial path dependence generates spatial water resource externalities between neighboring peri-urban villages. While existing scholarship has documented the economic dynamism of village-town industrialization and the environmental costs of cultural tourism, the spatial spillover of industrial pollution along shared waterways between adjacent villages remains underexplored. Using Tuhua Village (textile manufacturing) and Xiaozhou Village (cultural tourism and creative industries) in Haizhu District of Guangzhou as a comparative case study, this study employs semi-structured interviews with seven stakeholder types, archival analysis, and physical-chemical water quality tests across three monitoring sections. Fieldwork was conducted in February 2026. The findings reveal that path-dependent industrial divergence transformed shared water resources into pollution carriers in Tuhua and ecological assets in Xiaozhou, producing classic negative externalities due to incomplete water property rights. Current water quality data confirm that governance interventions–wastewater treatment infrastructure, pollution fees, and factory closures–have successfully contained industrial tracer pollutants (LAS, formaldehyde), though residual BOD_5 elevation indicates ongoing domestic pollution from both villages. The study demonstrates that while end-of-pipe regulation can internalize industrial pollution costs, equitable watershed outcomes require complementary cross-village ecological compensation mechanisms.

Keywords

Economics, Environmental economics, Industrial path dependence, Water resource externality, Urban village transformation

Article History

Received: 16 July 2026
Revised: 28 August 2026
Accepted: 31 August 2026
Available Online: 03 September 2026

1. Introduction

Unprecedented urbanization has transformed China since the reform and opening up era. As the core city in the Pearl River Delta, Guangzhou exemplifies the urban-rural transformation process [1]. In the course of urban expansion, peri-urban villages have been rapidly incorporated into the city, generating prominent challenges in industrial upgrading and resource-environmental conflicts. Village-town industry, a distinctive industrial form rooted in collective landownership and low-cost advantages, has become a flexible and efficient industrial cluster, but has also imposed considerable environmental pressure [2,3]. The textile and garment industry in Tuhua Village, Guangzhou, is a typical representation of this kind of village-town industry.

Guangzhou is a city built on and made prosperous by water. As village industries transform from agriculture to manufacturing and services, the role of water resources shifts accordingly: from irrigation input to pollution carrier, and finally to ecological asset and landscape resource. When an upstream village adopts a high-pollution manufacturing path while a downstream village pursues cultural tourism dependent on clean water, a classic negative spatial externality emerges [4,5]. The upstream pollution, flowing downstream without compensation, reflects the spatial dimension of market failure rooted in incomplete water property rights.

The existing scholarship on village-town industrialization in peri-urban China stresses its economic dynamism and institutional support, especially the role of collective landownership in enabling flexible production [2,3]. However, most of this work treats pollution as a local problem within the village itself, paying little attention to the spatial spillover of pollution along shared watersheds. Research on water resource governance has long established that the public-good nature of water and incomplete property rights lead to market failure, but this framework has rarely been empirically tested at the micro-scale of village-level industrial transformation [4,5]. Moreover, there are few studies comparing adjacent villages with natural endowments but with different industrial paths, and even less the environmental conflicts that such divergence generates. This study fills the research space in these gaps—between economic and environmental analysis of village industrialization, between upstream and downstream perspectives and between path dependence theory and environmental conflict.

As this paper tries to see how such conflicts happen empirically, I chose the adjacent villages of Tuhua and Xiaozhou in Haizhu District, Guangzhou. The two villages are geographically close, share the same water system and have very similar natural endowments, but followed two completely different development paths. Tuhua Village took industrial transfer, and developed some manufacturing industries such as textiles. Xiaozhou Village, because of a strict historic and cultural village conservation policy, developed service industries such as art, cultural tourism, and creative education. This is a very good natural experiment in order to see how industrial path dependence affects the water resource utilization and cross-village externality conflicts are generated.

In this study, I adopt a mixed-method field approach, combining participant observation with semi-structured interviews, archival analysis, and water quality testing, to address two research questions. First, how did two villages starting from a shared agricultural basis diverge into manufacturing and service paths? Second, how do these alternative industrial trajectories produce different patterns of water resource use that generate environmental externalities and how far have governance interventions internalized these costs? I argue that the upstream-downstream conflict between Tuhua and Xiaozhou is a typical case of negative spatial externality due to the incomplete property rights of water resources, and that the government has taken significant measures to internalize these externalities, including investment in wastewater treatment infrastructure, imposition of pollution fees, and factory closures, but there is still no cross-village ecological compensation.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature across four domains-village-town industrialization, cultural tourism development, path dependence theory, and water resource externality-and presents an integrated analytical framework. Section 3 describes the study area, data collection methods, and analytical approach. Section 4 presents the results and discussion, examining path dependence and industrial divergence (4.1), divergent river utilization and water resource externalities (4.2), and governance of externalities. Section 5 reports the water quality monitoring results and pollution source analysis. Section 6 concludes with policy implications, limitations, and future research directions. The role of digital technologies and innovation in supporting sustainable governance practices [6] is also considered where relevant.

2. Literature Review

The peri-urban villages and urban villages have commonly faced the problems of industrial transformation and resource-environmental conflicts [1] in the process of China's rapid urbanization, and the related research has formed a relatively mature body of discussion. Comparative research on sustainable development across China and neighboring countries further highlights the importance of context-specific governance approaches [7].

2.1 Village-Town Industrialization and Environmental Costs

First, concerning the studies on village-town industrialization, it has been found that the manufacturing clusters which depend on the collective land and low-cost rents are an important driver of the regional economic growth [3,8]. Generally speaking, industries like textiles and/or printing and dyeing come with high water consumption and high pollutant discharge, and they have prominent negative environmental externalities [9]. However, most of these studies consider pollution as a local problem of the village itself, and hardly pay attention to the pollution spatial spillover into the downstream communities of the same watershed. Recent studies have further examined the environmental regulation of textile wastewater [10] and the evolution of new industrial paths in peripheral regions [11], yet the spatial spillover of village-level industrial pollution onto neighboring communities within the same watershed remains insufficiently addressed. The broader landscape of legal and institutional reform in China, including frameworks for public interest litigation [12] and regulatory responses to emerging governance challenges [13,14], provides important context for understanding the evolution of environmental governance mechanisms.

2.2 Cultural Tourism-Led Rural Development

Second, the research on cultural tourism-led rural development suggests that the historical and ecological resources can bring about local change by attracting creative industries and building up the built environment [15,16]. This literature mainly focuses on the inside of tourism villages, almost not taking into account at all how such a development path is formed and how it suffers environmental pressures from neighboring industrial areas. Emerging research has examined the ecological threshold effects of rural cultural tourism development [17] and the relationship between rural tourism, economic growth, and environmental sustainability using county-level panel data [18], yet the environmental pressures imposed by neighboring industrial areas on cultural tourism villages remain largely unexplored.

2.3 Path Dependence Theory

Third, path dependence theory is useful to see why villages with the same starting point may turn out to be very different. The early choice of policy, the endowment of resources, and the signals from the market could lock in the industrial paths which, once locked, tends to be self-reinforcing [19,20]. For the peri-urban villages, this means that the manufacturing path has been locked in for Tuhua and the service path for Xiaozhou: not only will this structure their internal economies, but it will also generate cross-boundary environmental consequences, a dimension that research on path dependence has not yet covered. Recent scholarship has extended path dependence analysis to social-ecological systems in resource-based cities [21], providing mechanistic insights into how adaptive cycling perpetuates industrial trajectories, though the environmental conflict dimensions of path dependence at the village scale remain unexamined.

2.4 Water Resource Externality and Watershed Governance

Fourth, water resource externality is a core issue in environmental economics. Pollution discharge from upstream areas within a watershed causing environmental damage to downstream areas is a typical manifestation of negative externality, which is rooted in the unclear definition of water resource property rights and the failure to internalize pollution cost [4,5,22]. The existing research is mostly done at the scale of administrative regions or large watersheds, and there is no comparative analysis in mind of villages which are geographically adjacent but follow completely different industrial paths in the same ecological unit. Taken together, these four bodies of literature shed light on different facets of the problem this study addresses. Research on village-town industrialization documents the economic logic and environmental cost of manufacturing clusters, but ignores their spatial externalities. Cultural tourism studies show the developmental potential of ecological and heritage resources, but rarely think about how such assets are threatened by upstream pollution. Path dependence theory explains the industrial divergence but has not been extended to the environment conflict it generates. Research on water resource externalities provide the tools to analyze such conflicts but has not been empirically tested at the village micro-scale. This study brings these strands together by examining how two adjacent villages' completely different industrial paths which are shaped by path-dependent process produce spatial externalities through shared water resources. It then checks how the governance intervention has only half-solved such externalities, which points to the need of integrated watershed governance. Recent advances include collaborative governance models for watershed ecological compensation [23], multi-center governance systems for water resource ecological products [24], administrative collaborative governance of river basin water pollution under China's legal system [25], and the impact of environmental tax reform on industrial green development [26]. Trade policy and environmental law scholarship has also explored new approaches to greening economic agreements [27]. Despite these advances, the village-scale empirical testing of water resource externality frameworks remains rare.

2.5 Theoretical Integration and Analytical Framework

Systems thinking approaches to environmental policy, as applied in marine governance contexts [28,29], offer valuable methodological insights for analyzing the complex interactions between industrial activity and water resource sustainability.

The four bodies of literature reviewed above illuminate different facets of the problem this study addresses, but they remain disconnected in existing scholarship. This study integrates them into a unified causal framework with the following chain of reasoning: (1) Initial conditions-differences in resource endowments (cultural heritage vs. industrial land), policy constraints (conservation designations vs. industrial planning), and community aspirations-create divergent starting points for adjacent villages. (2) Path dependence and industrial lock-in-self-reinforcing mechanisms including switching costs, skill accumulation, supply chain development, and institutional embeddedness lock each village into a distinct industrial trajectory (manufacturing vs. cultural tourism). (3) Differential water resource utilization-the manufacturing path transforms water into a pollution carrier, while the cultural tourism path treats water as an ecological asset, creating fundamentally incompatible utilization patterns within the same watershed. (4) Spatial externality and conflict-upstream industrial pollution imposes uncompensated environmental costs on downstream communities, generating a classic negative spatial externality rooted in incomplete water property rights. (5) Governance and internalization-policy interventions (wastewater treatment, pollution fees, factory closures) internalize industrial pollution costs, though cross-village ecological compensation remains absent. This framework explicitly demonstrates how industrial lock-in perpetuates pollution and how clean-water dependence heightens downstream vulnerability, making the externality problem structurally intractable without integrated watershed governance. The causal link between path dependence and externalities-not merely asserted but empirically documented through fieldwork evidence and water quality data-constitutes the primary theoretical contribution of this study.

3. Methods

3.1 Study Area Profile

The case study sites are Tuhua Village and Xiaozhou Village, located in the southeastern part of Haizhu District, Guangzhou. I conducted fieldwork in both villages, using random interviews to understand the daily life, lived experience, and standpoint of the respondents on related issues. The study does not have any preestablished hypotheses, so the life experiences of villagers of different backgrounds will be understood. According to the principles of typicality, comparability and the accessibility already set in the existing research [30], Tuhua Village and Xiaozhou Village are chosen as case study sites. First, the two villages are in Guangzhou, and are easily accessible from my base in Shenzhen by high-speed rail, so I can do several rounds of fieldwork. Second, Tuhua Village borders Xiaozhou Village to the south. The two villages are in alluvial plain of the Pearl River Delta (Figure 1) and both of them are in the core area of the "Ten-Thousand-Mu Orchard" traditional agricultural system. The region has a dense network of rivers and streams. This complicated water network is the natural element which shapes the traditional pattern of production and daily life. From the point of view of physical geography, the two villages have highly homogeneous conditions in climate, soil and hydrology. It is the ideal basis for which to control the natural geographic variables in the subsequent comparative study of the villages' industrial paths. Third, the two villages have followed different industrial development paths. Before reform and opening up, the economic structures of two villages were dominated by orchard-based agriculture, the typical "fruit-based fishpond" eco-agriculture model. After reform and opening up, Tuhua Village followed the path of industrialization, but Xiaozhou village developed to be an ecological village, pursuing cultural tourism and service industries. This similar background and the striking divergence between the two villages have a great value for me to conduct an in-depth analysis of path dependence and water resource externalities.

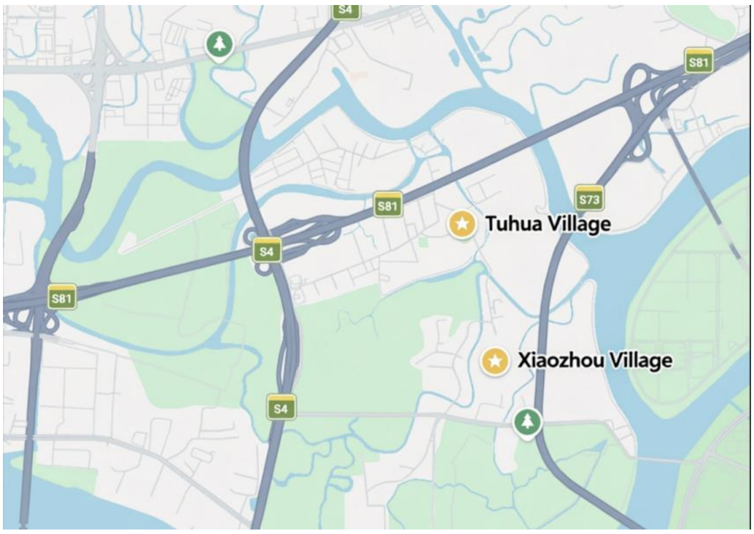

Figure 1. Relative location of Xiaozhou Village and Tuhua village. (Source: Google Maps)

3.2 Fieldwork Methods

This study employs a mixed-method field approach combining participant observation, semi-structured in-depth interviews, and archival analysis. Fieldwork was conducted in Tuhua Village and Xiaozhou Village, Haizhu District, Guangzhou, over approximately one month, encompassing semi-structured interviews, water sample collection, on-site visits, documentary filming, and participant observation. The semi-structured interviews were carried out during an intensive three-day period (9-11 February 2026). The total research duration, including pre-field archival research, fieldwork, and post-field laboratory analysis, spanned approximately three months. During the fieldwork period, theoretical sampling and snowball sampling were used to select informants with long-term knowledge of the villages' development as key informants, ensuring representativeness and information validity. In total, seven categories of stakeholders were interviewed: local villagers, landlords, enterprise owners, village committee cadres, artists, merchants, and tourists. All respondents were long-time residents or practitioners who could reflect the actual conditions of industrial transformation, water resource utilization, and environmental change in the two villages. All interviews were conducted with informed consent. Each interview segment lasted no less than five minutes, and all interviews were audio-recorded and fully transcribed, building a corpus of firsthand textual data. The field observation focused on industrial structure, business models, living and working environments, village landscape, ancient halls and cultural spaces, river and stream water quality, pollution discharge conditions, and ecological landscape differences between the two villages. On-site photographs and field notes were recorded simultaneously, providing visual evidence and factual support for the comparative analysis of industrial paths, water resource utilization differences, and externality conflicts. Information on the wastewater conveyance routes and the centralized treatment infrastructure serving both villages was obtained through field interviews and on-site observation during fieldwork.

3.3 Collection and Analysis of Documentary Materials

Through documentary research methods, I have systematically obtained policy documents, local gazettes, academic literature, and official reports of Tuhua Village and Xiaozhou Village, Haizhu District, Guangzhou. I traced the historical development trajectories, the industrial transformation process and the evolution of the relevant planning policy of these two villages. Through the induction of documentary content, the study shows the difference of the path of industrial development of the two villages, which is the basis of the analysis of the path dependence mechanism. At the same time, it also shows the functional changes of water resource in the different industrial stages, offering factual support to the later analysis of water resource externalities. The documentary materials were collected from the Haizhu District Archives, village committee records, Guangzhou municipal planning documents, and published local gazettes, covering the period from the early reform and opening up era (late 1970s) to the present.

3.4 Water Sampling and Chemical Analysis

In order to give quantitative evidence of the spatial externalities found in the qualitative analysis, I have run a water sampling and chemical analysis campaign. In total 8 water samples were taken from three sites of the shared water. Two were taken at the upstream section of Tuhua Village, being the reference before the industrial discharge. Three were taken at the downstream boundary of Tuhua Village, the point at which the water enters the section of Xiaozhou (the point in which the water coming from Tuhua is polluted by the manufacturing zone of Tuhua). Three were taken at the downstream section of Xiaozhou village to check the spatial diffusion. All samples of 1000 mL were taken in pre-cleaned brown glass bottles, kept at 4C and sent to the laboratory within 24 hours. The field sampling was conducted in February 2026, with samples transported to the laboratory within 24 hours for analysis. The complete laboratory testing cycle was approximately two weeks.

Since textile and garment manufacturing is the main branch of the industry in Tuhua Village, five parameters of the textile wastewater are chosen: the chemical oxygen demand (COD), anionic surfactants (LAS), formaldehyde, five-day biochemical oxygen demand (BOD_5), and the pH. The COD was determined by 25 mL burette according to the method of the dichromate titration (HJ 828-2017, the detection limit: 4 mg/L). The LAS was analyzed by automatic continuous flow analyzer (BDFIA-8100) according to the method HJ 826-2017 (the detection limit: 0.04 mg/L). The formaldehyde was determined by the method of visible spectrophotometry with a TU-1810 ultraviolet-visible spectrophotometer (HJ 601-2011, the detection limit: 0.05 mg/L). The BOD_5 was measured by the method of the dilution and seeding (HJ 505-2009, the detection limit: 0.5 mg/L). The pH was measured semi-quantitatively on the site with pH test strips. The blanks and duplicate samples are in the quality control, and all the analyses were controlled with the holding times of the corresponding standard methods.

4. Results and Discussion

4.1 Path Dependence and Divergence of Industrial Trajectories

4.1.1 Shared Agricultural Foundations and Resource Competition in the Pre-Reform Era

In the agricultural era, the two villages have adopted the "fruit-based fishpond" eco-agricultural model of composite production, which is a material recycling production system. This means they have dug ponds, built up raised dikes, planting fruit trees on the surface of the raised dikes while raising fish in the pond. Besides being a mode of livelihood, this method also constitutes the form of organization of the local society. According to the study on the building of the Jian lineage of Xiaozhou Village and the social change in the Pearl River Delta during the Qing dynasty, how the Jian lineage of Xiaozhou has been formed and expanded is tightly related to how the Jian lineage has controlled and managed the field of orchard-based lineage. The lineage genealogy records that "members both farmed and studied, prospering in studying", and the establishing of "study field" to subsidize the studying of the lineage's descendants means that over that time the agricultural output has been stable, so the material of this stable agricultural output is a foundational material for supporting the operation of the lineage's society and the development of culture and education [31]. It can be inferred that under the same geographic and climatic conditions, it can be expected that Tuhua Village would have the same kind of agricultural economic model and form of social organization. So in the arable era, the two villages have marked the homogeneity of the economic structure, mode of production, and community organization.

In the agricultural economy, the water resources and the resources associated with water, such as river silt, were core factors of production central to agricultural productivity. Water was used for irrigation and aquaculture. River silt is served as a kind of organic fertilizer, which is essential to the fertility of the dikes and the fruit trees. The control over and the competition for these two resources became the decisive factor shaping the historical relationship between the two villages of Tuhua and Xiaozhou. The most famous conflict between the two villages occurred in the Guangxu period of the Qing dynasty. The core of the dispute centered over river silt. As stated in the record of the General Genealogy of the Jian Lineage of Eastern Guangdong, in the Guangxu period of the Qing dynasty, the villages of Xiaozhou and Tuhua erupted in a large-scale armed feud over the right to dredge river silt. The villagers of Xiaozhou said that they were collecting silt from a public waterway. The villagers of Tuhua accused the other side of crossing the boundaries to take silt from the farmland of Tuhua. The conflict lasted for several years and resulted in casualties, before it was arbitrated by the magistrate of Panyu county. To this day there stands a government proclamation stele, about 1.6 meters in height, preserved in Tuhua Village. The inscription is partly legible: Proclamation issued on the fifth day of the tenth month of the seventeenth year of the Guangxu reign... clearing silence, armed feud. It is the physical testimony of the history (Figure 2). In a word, before their modern industrial transformation, Tuhua Village and Xiaozhou Village shared almost the same socioeconomic foundation. The stele inscription recording the donation for temple repairing of the Jian lineage of Xiaozhou in the Qianlong period, together with the official stele erected after the silt feud between the two villages in the Guangxu period, attest to the twin dimensions of internal cooperation and external competition, indicating the homogeneity of the two villages' economic structures and their deep dependence on the water and the land resources of this period. It provides the important historical premise of understanding why and how the two villages subsequently diverged during the wave of industrialization. Figure 2 presents the Stele of Prohibition on Armed Feuds in Tuhua Village, along with a schematic map showing the relative locations of Tuhua Village, Xiaozhou Village, and the stele. This historical artifact, dating from the Qing Dynasty, documents early conflicts over water and resource access between the two communities, providing evidence that resource competition between these villages has deep historical roots.

Figure 2. The Stele of Prohibition on Armed Feuds, Tuhua Village (Left). Schematic map showing the relative locations of Tuhua Village, Xiaozhou Village, and the stele (Upper right). The stone marker erected by the Haizhu District People's Government in 2012-2013, designating the stele as an Immovable Cultural Relic (Lower right). (source: https://mp.weixin.qq.com/s/WpJ0WOKREXt-MP1kY4E8BA?scene=1)

4.1.2 Initial Conditions for Industrial Divergence and the Formation of Path Dependence

The reform and opening up policy started in China in the late 1970s, which triggered a nationwide socioeconomic transformation. Against the backdrop of such macro-institutional change, Tuhua Village and Xiaozhou Village, though geographically adjacent, were directed to the different development tracks under a series of specific local factors and early in-house decisions. Tuhua moved from agriculture to manufacturing; xiaozhou moved gradually from agriculture toward service industries. Historical factors also helped in this divergence, which means that there is an emerging path dependence effect in the development of the region.

For Xiaozhou Village, the initial constraints on its industrial transformation came from two sources at most. First, the village kept a large number of the traditional buildings of the Ming and Qing dynasty (e.g. the “oyster shell” houses), an intact village fabric and a dense landscape of ancient trees. The above mentioned tangible cultural heritage resources made it the first to be recognized by the local authorities as a historic village that should be protected. Second, its location in the "Ten-Thousand-Mu Orchard" ecological zone ensured its ecological value gained increasing attention. In sum, these two factors endowed Xiaozhou with a functional designation of historical and cultural conservation, together with the ecological preservation, within regional development planning. This function designation was directly transferred to the strict restriction of industrial construction. Thus, Xiaozhou couldn't follow the mainstream path of rural industrialization to realize the economic transformation.

On the contrary, like many other urban villages in Guangzhou, Tuhua Village also has the nearest Zhongda textile cluster and began its industrialization path in the field of garment processing. The state of the preservation of the traditional building of Tuhua is also rather ordinary, so there are no strong historical constraints on cultural conservation. Furthermore, in the early spatial planning of industrial zones, the land of part of Tuhua was designated for industrial use. More importantly, in the face of small returns on agriculture, and the effect of the demonstration of industrialization of surrounding areas, a strong willingness to change in the face of hardship emerged in the Tuhua community, leading to the active search for non-agricultural employment and the growth of income. Therefore, when the external capital and technology, especially the "three-plus-one" processing and assembly industries of Hong Kong and Macau were transferred to the Pearl River Delta, Tuhua Village, taking advantage of the land space, the permissiveness of policy, and the receptiveness of the community, could absorb the transfer of manufacturing industries such as the textile, dyeing, leather and toys, and become an early entrant on the path of the industrialization among the villages of the countryside.

Thus, in the years of the very beginning of the reform and opening up, the two villages made different choices at key turning points, owing to their different endowments of resources (cultural and ecological resources or land suitable for industrialization), different external intervention of policies (conservation restrictions or industrial planning), and different internal development aspirations. These early choices had the effect of offering to paths in a forking road, and the structure of their later trajectories was born of these different choices: that is, the turn of Xiaozhou toward service industries, and the deep turn of Tuhua towards manufacturing. With self-reinforcing mechanisms, these trajectories are going to be more and more rooted as time goes on, which is a typical case of path dependence. Specifically, multiple self-reinforcing mechanisms locked each village into its trajectory. For Tuhua Village, these included: (1) high switching costs arising from the deep integration with the Zhongda textile supply chain, making relocation or industrial conversion economically prohibitive; (2) skill accumulation among the Hubei merchant community, whose specialized knowledge of garment production and market networks created path-specific human capital; (3) supply chain development, as upstream fabric suppliers and downstream logistics firms co-located around the manufacturing cluster, creating agglomeration economies; and (4) institutional embeddedness, whereby village collective organizations built standard factory workshops for rent and became financially dependent on manufacturing income, creating a structural incentive to maintain the industrial path. For Xiaozhou Village, the lock-in mechanisms operated through: (1) legal constraints, as heritage conservation designations imposed legally binding prohibitions on industrial construction; (2) resource-specific skill accumulation among artists and cultural practitioners who had invested in place-specific creative capital; and (3) ecological red-line restrictions associated with the Ten-Thousand-Mu Orchard zone, which precluded industrial land use. These mechanisms rendered industrial path reversal increasingly costly and unlikely for both villages.

4.1.3 The Industrialization Trajectory of Tuhua Village

The industrial transformation of Tuhua Village is also a classic history of rural industrialization within the background of an export-oriented economy. Before reform and opening up, just like Xiaozhou Village, the economic pillar of Tuhua Village was also the "fruit-based fishpond" agricultural system. With the change of national macro-policy, Tuhua Village, with its specific locational conditions and the community's aspiration, was successfully integrated into the wave of ‘three-plus-one’ processing and assembly industries and rural industrialization in the Pearl River Delta. In the late 1970s, the reform and opening up policy was implemented in China. Under the price scissors of industrial products and agricultural products, the relative returns from agriculture remained low [32]. Under the situation of the “three-plus-one” model, the coastal area has an important opportunity to use its land, factory premises, and labor to undertake international industrial relocation. At the same time, Tuhua Village also met the practical pressure of low returns from agriculture. Fruit cultivation was restrained further by natural and market fluctuation. These conditions gave the community a strong will to change.

The industrialization of Tuhua Village arose from the rise of the Zhongda textile commercial cluster. The Zhongda textile commercial cluster emerged in the early years of reform and opening up, leading to Haizhu District, Guangzhou gradually becoming the largest specialized wholesale market cluster of textile fabric, garment and textile accessories in China and generating great demand for downstream processing. Tuhua Village is located on the periphery of the cluster, and has adequate land with clear property right such that it is suitable for industrial use. It is very suitable for undertaking processing orders, absorbing the spillover effects of the textile industry. The earliest labor-intensive factories, such as toy and garment workshops, were built in Tuhua Village in the early 1980s. At the time, the industrial ecosystem had matured, and the garment making sector of Tuhua progressively deepened, forming a characteristic regional industrial cluster.

The merchants of Xiantao, originating from Hubei Province, played the most important role in this process. They set up a large number of small and medium sized factories. They also took part in deepening the process of integration and upgrading of the industrial chain. Some of the entrepreneurs took advantage of this mature supply chain and also the opportunity of e-commerce to develop into platform-based enterprises, orienting towards the global fast-fashion market and making the leap from contract manufacturing to an independent brand offering direct online retail. The industrial model also changed, from processing the materials supplied to it and then wholesale distribution to direct export via land routes and ports, finally becoming deeply embedded in the global internet retail supply chain. This deepening integration into the global fast-fashion supply chain created powerful lock-in effects: the specialized infrastructure, skilled labor pool, and established buyer-supplier networks constituted irreversible sunk costs that made industrial conversion increasingly impractical.

"The people doing garment business here are probably all from Hubei. I'm also from Hubei. I make leather shoes, all handmade, and the leather is sourced from elsewhere. I place orders directly with manufacturers, but there are probably no leather factories left in Tuhua itself. The taxes on those factories here are too high, so they've all moved to neighboring Panyu. I only run a physical store. Small shops like ours mainly rely on business from regular customers in the neighborhood. Online, platforms like Pinduoduo and Douyin can provide whatever style you want. The impact of online shopping on us is only moderate, because we don't target young people. We mainly target those who, how should I put it, want something more substantial. Young people like fashionable styles. They switch shoes every two weeks or every month, spending thirty to fifty yuan on a pair they'll wear for just a few days, so they won't come into a small shop like this. You can pick anything online that's far more fashionable than what we have. The general price in our shop is around ninety to one hundred yuan."

From a shoe store owner in Tuhua Village.

The industrialization of Tuhua Village was not a purely spontaneous market process; the local government and village collective organizations participated actively in it [33]. The government planned and constructed the industrial parks, guided the scattered enterprises into the zones, and managed the industrial space centrally. The economic cooperative and its subordinate cooperatives built the standard factory workshops for rent and took part in the park management so as to convert the benefits of industrial development into income for the collective and dividends for the villagers. Because of this deep participation, the local villagers broadly supported the development of the manufacturing; thus, there appeared a symbiotic model that outside entrepreneurs ran the factories, and the locals collected rents. This institutional arrangement created a structural dependency: village collective revenue and individual villager income became inextricably tied to manufacturing rent, making any attempt to shift away from the industrial path financially untenable for the community.

"Now the locals mainly live off the rent from those factories. In recent years, with the poor economic situation, rents have hardly increased, whereas in previous years they went up every year."

From a staff member of the Tuhua Village Committee.

On the other hand, the extensive industrial growth also incurred severe environmental costs, particularly during the pre-treatment period before adequate wastewater infrastructure was constructed. The processes of textile dyeing and printing produce a large amount of industrial wastewater, and population concentration generated substantial domestic sewage. Before intercepting sewer networks and treatment facilities were built, all these pollutants were discharged directly into the rivers. As recalled by elderly residents, the river water turned completely black and malodorous, aquatic ecosystems collapsed, and downstream agricultural production and ecological landscapes suffered serious negative externalities. This historical pollution represents the pre-intervention externality that motivated subsequent governance measures.

"Back in the 1980s, many locals raised cattle. The cattle waste was buried directly in the river. At that time, the river water was completely black and stinking."

From an elderly local surnamed Liang from Tuhua Village.

In recent years, the government has implemented a series of measures, including building intercepting sewer networks and conveying wastewater to treatment plants for centralized processing. Sewage from the Tuhua area is conveyed through the pipe network into Xiaozhou Village, where it is collected by the village's internal interception network and transferred to the Lijiao Wastewater Treatment Plant (Phase III), a municipal facility located immediately south of Xiaozhou Village, for centralized purification. These interventions have substantially reduced the discharge of industrial pollutants into the river system. The historical pollution legacy, however, remains an important context for understanding the trajectory of environmental governance in Tuhua Village and the evolution of its downstream externalities.

"Now all those sewage pipes have to be connected to the wastewater treatment plant, all the way to Xiaozhou. From the riverside, those large iron pipes are all connected, and water pumps are used to send them to Xiaozhou for unified

treatment. Now, all fecal waste is prohibited from being discharged into the river. The government has added the cost difference to the water bill. Now the water fee we pay in our village is over seven yuan. They charge us local landlords over seven yuan."

From an elderly local surnamed Liang from Tuhua Village.

The treatment facility referenced above is the Lijiao Wastewater Treatment Plant (Phase III), situated immediately south of Xiaozhou Village; Xiaozhou itself hosts no wastewater treatment plant of its own, serving instead as a transit point in the municipal conveyance network.

4.1.4 The Transition to Art, Cultural Tourism, and Service Industries in Xiaozhou Village

After the reform and opening up, in contrast to the industrialization path taken by Tuhua Village, Xiaozhou Village took service-sector development trajectory oriented around its cultural and ecological resources. The formation of this trajectory comes from the resource endowments of Xiaozhou binding the external policy constraints and the internal development dynamics of these forces. The start point of the industrial transformation of Xiaozhou is its historical and cultural endowments and its good ecological foundation. Concerning the historical background, Xiaozhou Village was built up during the late Yuan and early Ming dynasties. The Jian lineage has produced many successful candidates for the imperial examination, so it became known as the "Village of Jinshi" and kept a large number of traditional buildings in good condition, such as oyster shell houses and the Sihai Ancestral Hall [31]. At the same time, Xiaozhou Village is located in the core area of the Ten-Thousand-Mu Orchard wetland agricultural system, which is characteristic of the network of rivers and ancient banyan trees of the region, forming a particular Lingnan water town landscape [34]. These cultural and ecological resources are the core endowments of Xiaozhou, differing from Tuhua Village.

It was precisely because of these endowments that Xiaozhou Village was assigned the functional designation of historical and cultural conservation and ecological preservation zone early in regional development planning. For example, in 2000, Xiaozhou Village was listed among Guangzhou's first batch of Historical and Cultural Conservation Areas. In 2013, it was designated a Traditional Chinese Village by the Ministry of Housing and Urban-Rural Development alongside several other national ministries. The local government put the village under the protection of ancient village regulations and limited industrial construction, especially in a very polluting sector such as textile and leather. These legal designations created an institutional lock-in that functionally prohibited industrial development, channeling Xiaozhou's economic transformation exclusively toward cultural and service industries compatible with conservation requirements.

"Now the neighboring Xiaozhou Village has been designated as a Cultural Conservation Village by the state. Those ancient buildings are not allowed to be demolished; they are all protected."

From an elderly surnamed Liang from Tuhua Village.

This powerful external policy intervention foreclosed the possibility of Xiaozhou Village taking the same industrialization model as in rural areas, meaning it had to find an industrial development direction that is compatible with the conservation requirements. In the 1990s, the ancient village landscape of Xiaozhou, its waterside ambience, and its being very near to the Guangzhou Academy of Fine Arts attracted many artists like Guan Shanyue to settle and create there. Being discovered by the artist made Xiaozhou Village quite famous, and a spontaneous art village slowly developed. After the successful entrance of the art education industry and the cultural tourism industry, agriculture was replaced by those two as the two dominant sectors in the village. The presence of the Guangzhou Academy of Fine Arts created a self-reinforcing cultural cluster: as more artists settled, the village gained reputation as an art destination, attracting further creative practitioners and art education institutions. This cultural capital accumulation constituted a path-specific asset that would be difficult to replicate elsewhere, reinforcing Xiaozhou's service-sector trajectory.

"This place is run by a senior from our Guangzhou Academy of Fine Arts, so when we first wanted to establish our brand, we invited him to collaborate here. Inside, we run a calligraphy training institution, because this is the Xiaozhou Art Village after all. Xiaozhou Village is still one of the urban villages, so there are plenty of migrants. I'd say there are more young people because there are many art studios nearby, including postgraduate exam prep institutions and the like. So this place is rather mixed."

From a café owner in Xiaozhou Village.

In this way, Xiaozhou Village completed its transformation from an agricultural economy to a service economy, forming a service industry cluster based on artistic creation, training, and tourism experiences.

Nevertheless, the service-sector development path of Xiaozhou was also accompanied by a series of endogenous contradictions and external challenges. Though the art district is in the village, its management rights are generally in the hands of external companies, while the village collective and villagers do not receive the main distribution of the benefits. This has deprived villagers of the motivation to maintain and develop the arts industry, and even to fight with external artists and operators. The village's collective economy is weak; even the financial data show that its revenues barely account for expenditures. Thus, it is not able to make effective investment into its heritage conservation and tourism facilities. At the same time, the excessive expansion and vicious competition of the training industry have all pushed a giant flow-through of the institutions. In seeking their spatial demands, villagers have been increasingly in favor of unauthorized construction, which has also damaged the continuous landscape and original character of the ancient village [35].

Figure 3 illustrates the residential buildings and narrow alleyways of Xiaozhou Village, visually capturing the spatial pressures that tourism-driven population concentration places on the village's infrastructure, domestic sewage capacity, and water environment.

Figure 3. A photograph of residential buildings in Xiaozhou Village.

Environmental footprint of Xiaozhou Village's service economy: While the primary focus of this study has been on the industrial pollution externalities originating from Tuhua Village, a balanced analysis requires examining Xiaozhou Village's own environmental footprint. The transition to a cultural tourism and creative industries economy has generated its own set of environmental pressures that warrant comparable scrutiny. The rapid influx of artists, art students, tourists, and service-sector workers has dramatically increased the village's permanent and transient population, placing substantial pressure on its domestic sewage infrastructure, solid waste management capacity, and fragile historical water system. The BOD_5 data provide quantitative evidence of this footprint: the downstream BOD_5 of Xiaozhou Village (13.1 mg/L), while notably lower than that downstream of Tuhua Village (26.6 mg/L) due to natural self-purification along the waterway, remains nearly double the upstream baseline (7.0 mg/L). This indicates that the biological organic load from Xiaozhou's service-sector activities-cultural tourism, art studios, food service establishments, and residential population-constitutes a non-negligible pollution source in the watershed. Unauthorized construction by villagers seeking to capitalize on tourism demand has further damaged the traditional water system and village fabric [35], while the weak collective economy limits investment in domestic sewage treatment infrastructure. It is important to distinguish between the two types of pollution: Tuhua's historical industrial pollution was a structural, cross-regional externality imposing severe downstream damage, while Xiaozhou's service-sector pollution is a localized environmental pressure primarily affecting the village's own water environment. Nevertheless, both contribute to the cumulative BOD_5 burden in the watershed, and comprehensive water quality management must address domestic pollution from both villages alongside industrial pollution control.

Because of this construction-induced destruction, the artistic atmosphere of the village has degraded, and so some of the artists who have come here in the hope of finding a quiet creative environment have left. This has created a potential risk cycle of weakening ambience and industrial relocation. In the environmental dimension, industrial pollution has been avoided, but the population concentration brought by the service industry has produced large volumes of domestic waste and sewage. If not treated, these pollutants also threaten the water quality of local rivers and streams, which is another kind of negative water resource externality. In recent years, the policy focus of higher-level governments has further turned to ecological protection, and thus the orchards around Xiaozhou Village were unified, expropriated, and incorporated into the Haizhu National Wetland Park system for conservation. Though this move has further strengthened ecological protection, at the same time it means that the space for Xiaozhou Village to independently control its industrial development has been further restricted. How to regulate the training industry, improve the tourism quality and enable the village collective and the villagers to share more equitably in the benefits of the development without damaging the ecology or the historic sites, and to make the revitalization realize the restoration of the old to its former state, are the core challenges of the sustainable development of the service industry of Xiaozhou.

4.2 Divergent River Utilization and Water Resource Externalities

4.2.1 Divergent Water Use Patterns Across Industrial Sectors

After the reform and opening up, the economy of Tuhua Village was dominated by textile and garment manufacturing and dyeing. These industries carry a high pollution load and complex effluent composition. In textile dyeing and finishing processes, especially in the pretreatment stage such as desizing and scouring as well as the dyeing stage, a large amount of organic wastewater is generated. It has been proved in research that the chemical oxygen demand (COD) concentration of desizing wastewater can be several thousand or even tens of thousands milligrams per liter. Composite dyeing and finishing wastewater shows deep chromaticity, high salinity and poor biodegradability, which is a typical type of refractory industrial wastewater. In the early stage of industrial development, such wastewater which hasn't been well treated is discharged to rivers and streams directly. The organic substances and heavy metals (such as dyes, auxiliaries and sizing agents) it carries will quickly consume the dissolved oxygen in the water, making the rivers black and malodorous while destroying aquatic ecosystems. Such high concentration pollution discharge is the direct material source of the great negative externality that is imposed by Tuhua Village onto the regional water environment, and it also reflects the urgency of strict end-of-pipe treatment and whole process control after. After 1990, Tuhua Village was industrialized. Many garment factories, dyeing plants, toy factories, and leather factories were rapidly established. Industrial production not only consumes water resources, but also uses water as a carrier of pollutant discharge. Compared with traditional agriculture, manufacturing is far more severe in terms of both water consumption and water pollution. The wastewater is discharged from both spinning and dyeing/finishing of the textile. Textile wastewater is mainly generated in the pre-spinning processing and some weaving processes. Dyeing and finishing refer to the production processes of pretreatment, dyeing, printing and finishing applied to the textile materials (fibers, yarns, threads and fabrics). In the early phase of industrialization, the village and town industries were not conscious of pollution control, and much industrial wastewater was directly discharged into the surrounding rivers. In this stage, the water in Tuhua village was transformed from the resource into the discharge carrier.

Around the year 2000, Xiaozhou Village, with its special culture, had become a very famous historical and cultural conservation area. Due to its beautiful scenery and sound ecology, a large number of art practitioners came to Xiaozhou to settle, sketch, and even do art training, and the service sector gradually became a very important local industry. Different from the agricultural situation, the rivers in Xiaozhou became more and more landscape water, providing the local residents with a pleasant ecological environment, and thus the development of cultural tourism also became more and more popular. Though the population increased and the hundred-mu orchard agriculture still exists, the volumes of domestic and agricultural water use in Xiaozhou remained relatively small. At the same time, the demand for water quality rose steadily, and the importance of water has changed from the resource of production and daily life to a form of environmental capital.

4.2.2 The Changing Role of Water Resources

From the above discussion, it can be concluded that the human-water relationship in the Tuhua Village and Xiaozhou Village has also carried out the corresponding change, from the historical pattern of "competing for water and silt" to today's contradiction of "wastewater discharge and water body protection." In the development of the industries in Tuhua village, it discharged wastewater on a large scale so as to maximize production profits, while Xiaozhou Village tried to protect the water resources to get a better environmental return. In the modern era, the two different situations have generated even greater water-use conflicts between the two villages.

Table 1 systematically summarizes the functional differences of the surrounding river systems across the agricultural, industrial, and service stages of production for both villages.

Table 1. Functional differences of the surrounding river systems across different stages of production.

Stage of Production	Relevant Village(s)	Function of Surrounding Rivers
Agriculture	Xiaozhou, Tuhua	Factor of production
Industry	Tuhua	Pollutant discharge carrier
Service sector	Xiaozhou	Ecological asset

Note: Table 1 presents a comparative analysis of river system functions across three production stages (agricultural era, industrial era, and service era) for Tuhua Village and Xiaozhou Village. The functional roles of water resources are categorized by primary use pattern, pollution source, and downstream impact. Data sources: fieldwork observations, semi-structured interviews with village residents and committee members, and archival records from Haizhu District local gazettes.

4.2.3 Water Resource Externalities

Externalities refer to situations in which the actions of one economic agent affects others, without such effects being reflected through market prices. If the behavior of an individual economic unit imposes impacts on society or on other individuals (for instance, environmental pollution), without the corresponding obligations being borne by that individual or the furnishing of corresponding compensation, these effects are also called external costs, external effects or spillover effects.

The industrial production in Tuhua Village has a long history of creating large negative externalities on water resources. In the pre-treatment period, textile manufacturing and garment production factories discharged untreated wastewater directly to the rivers, affecting the whole river and stream system, and imposing large external costs on the surrounding environment and downstream communities. However, the cost of such externalities–the damages to water pollution, ecological degradation, and downstream economic losses–was not borne by the polluting enterprises but externalized to the environment and neighboring villages like Xiaozhou. Externality theory states social cost = private cost + external cost. In the past, the factories in Tuhua Village only considered private costs (such as factory rent, factor costs, and labor costs), while the environmental costs of water pollution were paid by the downstream communities without compensation. In recent years, governance interventions such as wastewater treatment, pollution fees, and factory closures have internalized these external costs significantly, which is confirmed by the current water quality monitoring results in Section 5.

From the perspective of environmental economics, the root of the externality problem is often that the property rights are not well-defined. Water resources are a quasi-public good which is rivalrous but weakly excludable, so the property rights regime of water resources is not complete. In China, ownership of the water resources belongs to the state. However, the specific rights of using, benefitting from and disposing of the water are not clearly or effectively defined and allocated. When each economic agent, e. g., the factories in Tuhua, wants to maximize its own benefit, it will tend to use or pollute public water resources while not taking on the full social cost. Its private production cost is much lower than the true social production cost, and the difference between the two is a negative externality which is imposed on third parties, e. g., downstream Xiaozhou Village. So, the conflict between Tuhua and Xiaozhou about the resource utilization of water is just the typical manifestation of the divergence between the private and social costs caused by the inadequate property rights system.

Figure 4 shows the negative production externality of Tuhua Village. The downward-sloping demand curve (Demand) is the consumers' marginal benefit (MB) of the textiles of Tuhua. The lower supply curve is the marginal private cost curve (MPC), that is, only the enterprises' own production cost, not including the external environmental cost of the water pollution generated in the production process. The upper curve is the marginal social cost curve (MSC), which equals to the sum of private cost and external cost; that is, social cost = Private cost + External cost, where the external cost is the water environmental damage caused by the textile production of Tuhua to the downstream such as Xiaozhou Village. In the figure, *Q** is the point of the market equilibrium, that is, the point of the privately optimal output: because the enterprises do not carry the full environmental cost, this output is far higher than the social optimum. *Qs* is the social optimum, that is, the point of the efficient level of the output which takes all private and external costs. It is seen that when the enterprises of Tuhua make decisions according to their own cost and benefit, overproduction happens as a form of market failure, putting the environmental costs of water pollution on the downstream Xiaozhou, which depends on clean water sources. This is the classic pattern of negative spatial externality, in which the upstream pollution imposes an uncompensated cost on the downstream community. The deadweight loss triangle (shaded area between Qs and Q*) represents the welfare loss to society from overproduction-the environmental damage that exceeds what would occur at the socially efficient output level. This graphical framework demonstrates that without governance intervention, the market equilibrium produces more textile output than is socially optimal, with the excess pollution cost borne by downstream communities.

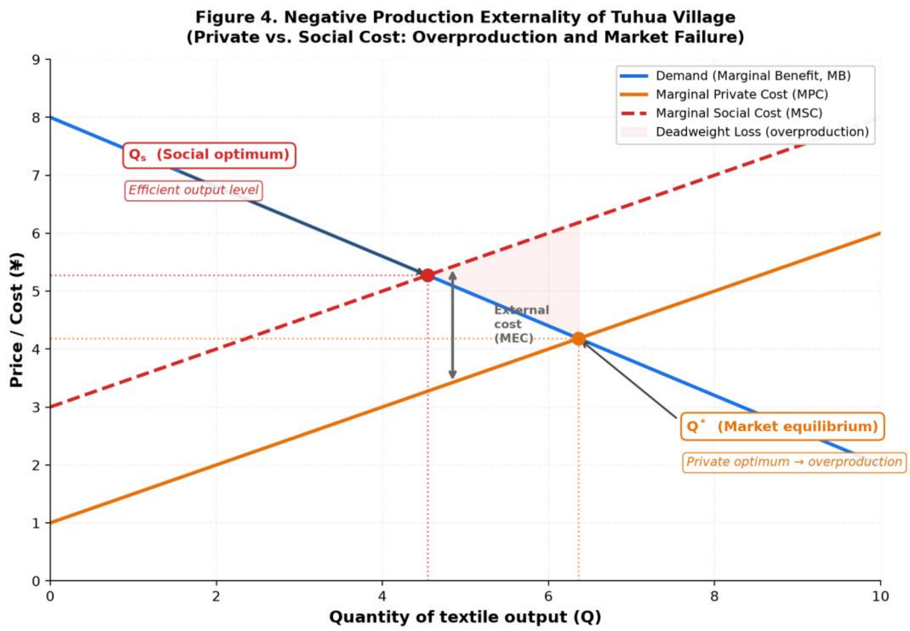

Figure 4. Supply and demand graph for Tuhua Village.

From the spatial perspective, Tuhua Village is upstream of Xiaozhou Village. This geographical pattern renders upstream pollution spatially transmissible, producing a classic spatial externality in the environmental economic sense. Since the rivers is the carrier that is flowing continuously, naturally the pollution generated by Tuhua is transported downstream to Xiaozhou. In water rights theory, such spatial externalities are called "third-party effects of water rights transactions". That is, Tuhua, as the upstream water user and polluter, changes the quantity (reduces the quantity of clean water available) and the quality (increases the pollution load) of shared water resources without negotiation with or compensation to the downstream Xiaozhou, which is of the substantial damage of the service industry and the agriculture of the latter since both are deeply dependent on high-quality water resources. This effect highlights the difficulty of special governance. The economic development of Tuhua is deeply dependent on the industrial system of textiles, and the pollutant discharge is an ineluctable by-product of its production. In contrast, the economic development of Xiaozhou is deeply dependent on the service sector in which culture and tourism is dominant, for which the clean body of water and the beautiful environment are core assets. Thus the two villages are found to be in fundamental conflict over both the mode of water resource utilization and their governance demands: one needs to use the water as a pollution carrier to lower costs, the other needs to preserve the water as an ecological asset to create value. Any simple, one-size-fits-all governance can hardly satisfy the needs of both villages at the same time. Differentiated policies which coordinate the interests of upstream and downstream and internalize the spatial external costs must be designed to resolve this structure contradiction.

The above externalities are caused by the problem of poorly defined property rights. In Tuhua, if the textile, dyeing, and other manufacturing entities pursue profits, they only consider their own private costs, like the rent of the factory, raw material, and labor, but do not consider the cost of discharging the pollutants into the public water body when making their decisions. In environmental economics, the total social cost is the sum of the private cost and the external cost. The reason is that the private costs of the production activities of Tuhua are far lower than the true social costs. It is exactly the ambiguous ownership of the property right of water resource. Legally, the ownership of water resources belongs to the state in China, but the exclusive usage rights and the benefit rights are not clearly defined. This “common pool resource” characteristic incentivizes every factory to use the river as a free pollution carrier. Downstream Xiaozhou, in order to keep the clean water and the ecological landscape on which the livelihood of the village depends, such as the water-town scenery that attracts artists and the clean water sources needed for the maintenance of the orchards, is forced to bear the pollution costs imposed by the upstream activities. The divergence of the private cost and the social costs is a classic manifestation of market failure. It is exactly the reason why the two villages are locked in the sharp opposition of "upstream pollution, downstream suffering". In the process of the fieldwork, the sigh of the old local from Xiaozhou - "There's no comparison, no comparison at all," is the embodiment of the deep frustration with this institutional inequity and the enormous development gap. As they do not have the power to change the upstream polluting behaviors, they can only passively endure the resulting ecological and economic disadvantages.

4.2.4 Governance of Water Resource Externalities and Policy Effects

To offset the negative water pollution externalities of the textile, dyeing, and garment industry in Tuhua Village, the government has undertaken a set of governance measures, such as building wastewater treatment facilities, river- and stream-intercepting sewer projects, levying wastewater fees, and closing the most polluting enterprises. The corresponding policies are government regulation, public environmental governance, Pigouvian taxes, and public infrastructure investment, respectively. The core of the policies is to internalize the external environmental costs originally borne by the downstream Xiaozhou Village, so that the private costs would be closer to the social costs, thus alleviating the market failure. From a political economy perspective, the distributional asymmetries of the cost incidence of these governance measures are important. The infrastructure, which was capital intensive, for example wastewater treatment plants and intercepting sewer networks, was funded mainly by district-level government fiscal expenditure, spreading the cost across the wider public. However, pollution fees were charged to the manufacturing operators in Tuhua Village, and Tuhua's households additionally pay a monthly sanitation surcharge of approximately seven yuan per water meter—appended to their water bills, as reported by interviewees—to fund the centralized conveyance and treatment system, internalizing part of the external cost at the source. Significantly, there is no mechanism for compensating downstream Xiaozhou Village, which has long suffered the uncompensated environmental damage of upstream industrial pollution. Water quality has improved but the legacy of ecological debt from decades of untreated pollution discharge, a major transfer of environmental cost from the upstream industry to the downstream community, has never been measured or compensated for.

From the perspective of the economic mechanisms, the governance policies improve water resource externalities via two paths. First, the construction of the wastewater treatment plants and the intercepting sewer projects represents an end-of-pipe treatment and a public investment. It can reduce the pollution intensity generated in per-unit of output, and thus reduce external costs. Since the marginal social cost satisfies the condition that MSC = MPC + External cost, then the reduction of outside costs lets the curve of MSC move downward, while the curve of the marginal private cost MPC is unchanged. Thus, the output of socially optimum Q s' move rightward, close to the market equilibrium output Q, and the deadweight loss caused by the negative externality is obviously reduced, and the market failure is alleviated. Second, the levying of the wastewater fees, which is the form of Pigouvian tax, and the mandatory closing of highly polluting enterprises, is the internalization of externality by raising the private cost. The wastewater fees can increase the enterprise production cost directly, and compel the enterprise to bear part of the environmental costs. The closing of highly polluting enterprises, an example of administrative regulation, can greatly increase the marginal cost of pollution production, and thus force the inefficient capacity out of the market. Taking the wastewater fees as an example, the private supply curve MPC will move upward by an amount equal to the external cost per unit of output. Under the ideal conditions, it can bring MPC into full the alignment of MSC. In this process, the social cost curve MSC is not changed, the market equilibrium output will move leftward from Q to the output of socially optimum Q s, and the negative externality is effectively internalized. In terms of benefit distribution, the governance model produces differentiated outcomes: Tuhua Village's enterprises and village collective continue to capture the economic rents of manufacturing activity while bearing only partially internalized pollution costs; Xiaozhou Village, despite having suffered historical ecological damage, receives no compensatory transfers for its role as the downstream environmental beneficiary of upstream treatment investments. As a village committee staff member from Tuhua noted, "Now the locals mainly live off the rent from those factories", illustrating how collective economic dependence on manufacturing creates political resistance to more aggressive pollution control. Meanwhile, a café owner in Xiaozhou observed that tourism revenue depends entirely on clean water and scenic quality, yet the village has no institutional channel to claim compensation for the historical pollution damage it absorbed. This distributional imbalance highlights a critical policy gap: while the current governance framework successfully addresses water quality indicators, it does not address the equity dimension of historical environmental cost allocation between upstream and downstream communities.

From the perspective of public economics, this arrangement constitutes a textbook case of externality internalization through public provision: the municipal government invested in the treatment infrastructure as a public good, polluters in Tuhua bear the treatment costs through pollution fees and sanitation surcharges, and downstream Xiaozhou—whose orchards, soil, and fruit yields had long suffered from upstream pollution—now enjoys the restored water environment without bearing treatment costs. Centralized municipal governance has therefore not only contained industrial pollutants but also, to a considerable degree, alleviated the long-standing inter-village tension over water pollution.

Overall, the policy mix described above corrects the market failure from two dimensions at the same time: that is, it reduces the external costs while raising the private costs. The MSC curve would shift downward while the MPC curve would shift upward. This drives private optimal decisions to converge with the socially optimal level. In this governance model, the allocative efficiency of the water resources in the watershed is also enhanced, and the water resource conflict between Tuhua and Xiaozhou arising from their upstream and downstream industrial divergence is also alleviated significantly, which achieves the Pareto improvement at the watershed level. However, the current governance model exhibits notable limitations. First, the policy mix relies heavily on end-of-pipe treatment and administrative regulation, without establishing a market-based ecological compensation mechanism between upstream and downstream villages. Second, the pollution fee structure, while functioning as a Pigouvian tax, does not differentiate charges according to the spatial sensitivity of receiving waters or the cumulative ecological debt owed to downstream communities. Third, enforcement consistency remains a concern, as economic downturns create pressure to relax environmental oversight to sustain manufacturing employment and collective income. These limitations point to the need for a more comprehensive, equity-oriented governance framework.

Table 2 summarizes the economic classification and core principles of the governance measures applied in Tuhua Village, categorizing them by policy type and internalization mechanism.

Table 2. Economic classification and core principles of different policy measures.

Policy Measure	Economic Classification	Core Principle
Mandatory closure of highly polluting enterprises such as dyeing factories in Tuhua Village	Government regulation	The government directly restricts and prohibits polluting production activities, reducing negative externalities at the source.
Construction of a wastewater treatment plant in Xiaozhou Village	Publicly provided environmental governance (End-of-Pipe Treatment)	The government provides public environmental infrastructure to directly reduce pollution emissions and lower external costs.
Levying additional wastewater fees on villagers and enterprises in Tuhua Village	Pigouvian Tax	A tax is imposed on entities that generate negative externalities, internalizing the external costs and bringing private costs closer to social costs.
Intercepting sewer projects (river and stream sewage interception, pipe network retrofitting)	Public infrastructure investment	The government mandates the construction of intercepting sewer networks to sever pollution diffusion pathways; its essence lies in administrative intervention combined with public investment to reduce external costs.

Note: Table 2 classifies the four categories of water pollution governance measures according to environmental economics frameworks. Government regulation refers to mandatory administrative orders; public environmental governance denotes collective action for environmental protection; Pigouvian taxes include pollution fees levied on polluting enterprises; and public infrastructure investment encompasses wastewater treatment facilities and intercepting sewer networks. The core principle column identifies the primary mechanism through which each policy type internalizes external environmental costs. Data sources: fieldwork interviews, Haizhu District government policy documents.

5. Water Quality Monitoring and Pollution Source Analysis

I selected five parameters indicative of textile wastewater: COD, LAS, formaldehyde, BOD5 and pH. LAS is a characteristic pollutant of textile printing, dyeing and scouring. It is a core tracer of highly polluted textile effluents.

BOD5 is a biodegradable organic load from domestic sewage and light organic processing wastewater. COD is a total organic pollutant. Formaldehyde is a typical residual of textile fixing agents. pH is the acid-base balance and key for irrigation and ecological suitability.

In all the three monitoring sections, LAS were not detected in the monitoring results. Field investigation shows that there are high-LAS emission processes such as textile printing and dyeing and scouring in Tuhua Village. This result proves that the sewage treatment facilities of the village have good removal efficiency for the textile-characteristic pollutant. The wastewater of the highly polluting processes is stably discharged up to the standard after centralized treatment, and there is no LAS pollutant discharged.

COD shows a continuous downward trend along the water flow, from 34.5 mg/L in the water in the upstream section, to 26.3 mg/L downstream of Tuhua Village, and further to 25.3 mg/L downstream of Xiaozhou Village. This means that the drainage of Tuhua Village does not add new total organic pollution load, and the centralized sewage treatment facilities have an effect on reducing organic pollutants. The formaldehyde concentration is stable at 0.06 mg/L upstream and downstream of Tuhua Village and is not detected downstream of Xiaozhou Village. This concentration is the background value of the watershed, which can be degraded by natural water self-purification, and there is no new emission source in the village.

The BOD_5 rises from 7.0 mg/L in the upstream section to 26.6 mg/L downstream of Tuhua Village, an increase of nearly fourfold. However, this change is not accompanied by the typical characteristics of industrial wastewater discharge, such as a simultaneous sharp increase in COD, detection of LAS, or drastic pH fluctuation. This pattern indicates that the elevated BOD_5 is attributable to domestic sewage and scattered non-characteristic organic wastewater, rather than to discharge from core textile manufacturing processes. Notably, the BOD_5 decreases to 13.1 mg/L downstream of Xiaozhou Village—approximately half of the Tuhua downstream level but still nearly double the upstream baseline (7.0 mg/L). This decline reflects natural self-purification of the waterway between the two villages, while the residual elevation above the upstream baseline suggests that Xiaozhou's own service-sector activities—cultural tourism, art studios, and resident population—also contribute biological organic load to the watershed. This finding underscores that residual water quality concerns in the watershed stem primarily from domestic rather than industrial sources, reflecting a successful shift from severe historical industrial pollution to manageable domestic pollution following governance interventions.

pH displays an optimizing trend along the water flow. The upstream pH of 5.5-6.0 is a weakly acidic natural background. After drainage from Tuhua Village, the pH is adjusted to the neutral state of 7.0-7.5, which reflects directly the acid-base neutralization effect of centralized sewage treatment and the buffering effect of municipal pipe network drainage. The pH downstream of Xiaozhou Village is 8.0-8.5 (weakly alkaline). It is all meeting the water quality requirement of water for agricultural irrigation, and is suitable for ecological landscape and agricultural production use.

According to the collaborative changes of multiple indicators and pollution source analysis, the sewage treatment facilities in Tuhua Village have effectively controlled the characteristic pollutants of core industrial processes such as textile printing, dyeing, and scouring. No illegal discharge of highly polluting industrial wastewater was detected. This represents a significant governance achievement: the severe historical pollution that once turned rivers black and malodorous has been substantially remediated through intercepting sewer networks, centralized wastewater treatment, and pollution fee collection. The residual BOD_5 elevation reflects domestic sewage inputs from both Tuhua and Xiaozhou, a common challenge in peri-urban villages experiencing population concentration. The water environment conflict between the two villages has transitioned from severe industrial externality to manageable domestic pollution, demonstrating that the governance measures have successfully internalized the industrial pollution costs that historically imposed substantial negative externalities on downstream Xiaozhou Village.

6. Conclusion

This study compares two villages, Tuhua and Xiaozhou in Haizhu District, Guangzhou, to explore how path-dependent industrial trajectories produce differential externalities of water resources and how governance interventions address the conflicts. Despite having the same natural endowments in the same watershed, the two villages chose different development trajectories because of differences in initial resource endowments, policy constraints and community aspirations.

First, the divergence is driven by industrial path dependence. Tuhua Village was locked into textile manufacturing and Xiaozhou Village into cultural tourism and creative industries through several self-reinforcing mechanisms, including supply chain integration, skill accumulation, institutional embeddedness, and legal constraints. This lock-in generated fundamentally incompatible water utilization patterns. The path dependence framework, when extended to environmental outcomes, reveals how initial industrial choices create enduring ecological consequences that are difficult to reverse.

Second, the historical pollution from Tuhua's manufacturing sector produced large negative spatial externalities, imposing uncompensated environmental costs on downstream Xiaozhou. This externality arose from incomplete property rights over water resources, where upstream firms internalized only private production costs. The current water quality data demonstrate that governance interventions have successfully internalized characteristic industrial pollutants, transitioning the management challenge from industrial to domestic water quality control.

Third, while the policy mix of wastewater treatment infrastructure, pollution fees, and factory closures has reduced industrial externalities, the governance framework lacks a cross-village ecological compensation mechanism to address historical environmental debt and ongoing distributional inequities. This study contributes to: (1) establishing the causal relationship between industrial path dependence and environmental externalities at the village micro-scale; (2) integrating four previously separate literatures into a single analytical framework; and (3) demonstrating that governance interventions can internalize industrial pollution costs but require complementary equity mechanisms for fully sustainable watershed outcomes. These findings resonate with broader comparative studies of sustainable development and governance in China and other developing economies [7].

6.1 Policy Limitations

Despite the demonstrated success of governance interventions in internalizing industrial pollutants, the current policy framework exhibits several limitations. First, the governance approach relies predominantly on end-of-pipe treatment and administrative regulation, lacking a market-based ecological compensation mechanism that would require upstream polluters to directly compensate downstream communities for historical and ongoing environmental damage [23,24]. Second, the pollution fee structure, while functioning as a Pigouvian tax [26], does not account for the spatial sensitivity of receiving waters or the cumulative ecological debt accumulated during the pre-treatment period. Third, the administrative boundaries of governance-organized at the district level-do not align with the hydrological boundaries of the watershed, creating jurisdictional fragmentation that impedes integrated water resource management [25]. Fourth, the absence of quantified ecological damage assessment means that the historical environmental cost transferred from upstream industry to downstream community remains unmeasured and unaddressed. Finally, enforcement consistency is vulnerable to economic pressures, as downturns in the manufacturing sector create political incentives to relax environmental oversight to preserve employment and collective income. The need for stronger legal frameworks to support public interest litigation in environmental matters, as examined in the Chinese legal context [12], further underscores the gap between existing regulatory tools and the demands of cross-jurisdictional watershed governance.

6.2 Future Research Directions

This study opens several avenues for future research. First, comparative studies across multiple peri-urban village pairs in different Chinese cities would test the generalizability of the path dependence-externality framework established here. Second, quantitative estimation of ecological compensation standards-using contingent valuation or choice experiment methods-could provide evidence-based benchmarks for cross-village payment schemes [23]. Third, the integration of digital monitoring technologies, including real-time water quality sensors and satellite remote sensing, could enable continuous tracking of spatial externalities and treatment effectiveness. Fourth, longitudinal research tracking the welfare effects of governance interventions on both upstream and downstream communities would illuminate the distributional dynamics of environmental policy. Fifth, the theoretical framework integrating path dependence with environmental externality could be extended to other resource commons scenarios, such as air pollution spillovers between industrial and residential zones [11,21]. Digital technologies, including blockchain and artificial intelligence, offer promising tools for enhancing the transparency and efficiency of environmental dispute resolution and sustainable business practices [6,29], and their application to watershed governance warrants systematic investigation.

6.3 Recommendations

Based on the findings, this study offers the following policy recommendations. First, establish a watershed-level integrated governance framework that transcends village administrative boundaries, ensuring coordinated water resource management across upstream and downstream communities [25]. Second, implement a cross-village ecological compensation mechanism in which upstream manufacturing operators pay a watershed protection fee that is transferred to downstream conservation-dependent communities, internalizing the spatial externality through market-based instruments [23,24]. Third, adopt differentiated industrial management policies: for manufacturing villages like Tuhua, strengthen pollution source control and promote clean technology adoption; for cultural tourism villages like Xiaozhou, invest in domestic sewage treatment infrastructure to address service-sector pollution footprints. Fourth, establish a comprehensive, long-term water quality monitoring network covering all critical sections of shared waterways, enabling data-driven assessment of governance effectiveness and early warning of pollution incidents. Fifth, develop a quantified ecological damage assessment protocol to establish baseline conditions and measure the ongoing costs and benefits of governance interventions, providing an empirical basis for equitable cost-sharing arrangements. Lessons from governance failures in other sectors, including the importance of regulatory oversight and adaptive policy frameworks [36] and the value of systems thinking in environmental policy design [28], further support the case for integrated, watershed-level governance reform.

Acknowledgements

I am deeply grateful to Dr. Xueting Pan, for reviewing my paper and offering thoughtful suggestions on sentence flow. I also thank the Southern University of Science and Technology for providing laboratory resources that enabled me to complete the chemical water quality testing. Last but not least, my sincere thanks go to every resident from Xiaozhou and Tuhua I encountered during my fieldwork. Their willingness to share their stories gave me a profound understanding of the two villages and their intertwined history.

Author Contributions

As the sole author, Jiaming Fan was responsible for all aspects of this research: conceptualization and study design; fieldwork investigation, including semi-structured interviews, participant observation, and water sample collection; archival research and documentary analysis; physical-chemical water quality laboratory analysis and data interpretation; manuscript drafting, revision, and final approval. The author confirms that she has read and approved the final manuscript and takes full responsibility for its content.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

Ethics Statement

Ethical approval was not required for this study according to institutional guidelines because the research involved anonymous survey data and posed minimal risk to participants.

All figures in this manuscript are used with appropriate permissions and are free of copyright infringement. Figure 1 uses a publicly accessible Google Maps base for academic, non-commercial purposes. Figure 2 (the Stele of Prohibition on Armed Feuds) is based on field photography from the internet; the stele is a district-level immovable cultural heritage site of Haizhu District. Figure 3 (residential buildings in Xiaozhou Village) is an original photograph taken by the author during fieldwork. Figure 4 (supply and demand externality diagram) is an original illustration created by the author. No third-party copyrighted images are used in this manuscript.

Conflict of Interest

The author declares no conflict of interest.

Generative AI Statement

Generative AI tools were used only for language editing and grammar improvement. The author takes full responsibility for the content of this manuscript.

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