

Article

Street Store Spatial Configurations as Indicators of Socio-Economic Embeddedness: A Dual-Network Analysis in Chinese Cities

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Abstract

Street networks shape urban dynamics. However, at the important meso- and micro-scales, a research limitation remains in systematically linking the spatial logic of streets to the physical configuration of street-level commerce, in particular through an analytical lens that distinguishes between different urban network functions. With a view to overcoming this limitation and extending space syntax theory into the fine-grained analysis of commercial form, this study applies its dual-network logic, contrasting foreground networks and background networks. The spatial patterns of street stores were analyzed across eight street segments in four Chinese cities: Tianjin, Nanjing, Zhengzhou, and Hong Kong. Network types were distinguished using Normalized Angular Choice and patchwork pattern analysis. By using 2019 POI data, Street View imagery, and field surveys, a comparative quantitative analysis was conducted across three metrics: operation methods, functional diversity, and 100-m density. The results indicate differences: chain stores hold a clear advantage in high-value segments of the foreground network, a pattern supported by statistical tests. These segments also exhibit higher functional diversity (mean ENT = 5.12). In contrast, high-value street segments of the background network exhibit a consistently higher prevalence of sole stores. They also have a commercial density approximately 2.6 times greater than that of their foreground counterparts. These findings provide empirical evidence on how foreground and background networks support different kinds of commercial ecologies: one oriented toward micro-economy efficiency and standardized supply, the other toward socio-culturally embedded, high-intensity local exchange. Consequently, by linking specific street spatial configurations to measurable commercial outcomes, this research contributes methodologically by operationalizing the dual-network framework at a novel scale and offering a replicable analytical tool for diagnosing and guiding commercial spatial planning in cities.



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1. Introduction

The configuration of urban street networks is the fundamental skeleton of cities and serves as the primary conduits for movement, resource allocation, and socio-economic

exchange [1–5]. Within this system, streets integrate diverse urban elements, such as residents, commerce, and services, into a cohesive spatial system, profoundly influencing economic vitality and socio-cultural identity [6,7]. In this paper, the term “street store” refers to retail store or service establishment with ground-floor entrances accessible from the street, explicitly excluding temporary vending formats such as mobile stalls or food trucks. They are the nodes wherein spatial structure and urban life interacts with each other [7–9]. The existing research on the relationship between street spatial structure and street stores is primarily in two aspects. The first, dealing with space syntax and related urban morphology studies, focuses on how street network configuration influences pedestrian movement and commercial accessibility, revealing the fundamental role of spatial structure in shaping the daily activities [10–16]. The second domain, comprising geographical and economics research, analyzes the distribution of commercial establishments, concentrating on the market mechanisms and demand structures underlying locational choices [17–27]. Nevertheless, the earlier studies, predominantly conducted from behavioral, economic, or social perspectives, lack an analytical framework that enables a systematic integration of different commercial logics at the level of street spatial structure. Particularly at the meso- and micro-scales, it has not yet fully elucidated how different types of streets, through variations in their spatial configuration, influence store formats and their socio-cultural functions [28,29].

The dual network logic of Space Syntax provides a valuable framework for this investigation. It delineates two distinct structures: the foreground network, characterized by long, connected lines that facilitate movement and underpin micro-economic activities, and the background network, composed of short, clustered lines that support locally embedded socio-cultural life [30]. Based on natural movement theory, this binary suggests that spatial integration is associated with economic or cultural opportunities [31]. Although Space Syntax has been extensively applied in the analysis of urban morphology and traffic planning [32,33], it has been less frequently employed to examine store distribution at finer spatial scales, limiting its capacity to illuminate how spatial structure mediates urban processes.

Within the context of rapid urbanization in China, street stores function as crucial elements for both maintaining commercial resilience and preserving cultural continuity; however, their intrinsic relationship with urban spatial form is frequently overlooked in prevailing planning paradigms [34–36]. The need to revitalize micro-economies and the social fabric in the post-COVID-19 period reinforces a finer understanding of the problem [37]. In the existing research applying space syntax to the analysis of commercial establishments, street network is treated as a homogeneous system through topological metrics such as integration and choice, with widespread consensus confirming a macro-scale positive correlation between higher street centrality and commercial agglomeration intensity [12,13,15,24–26,38–41]. Nevertheless, this explanatory model has limitations at meso- and micro-scales. It fails to reveal the inherent heterogeneity in the composition of commercial activities: cities contain both high-capacity, movement-oriented corridors and fine-grained streets embedded in daily life. Treating these as functionally equivalent overlooks the systematic differences in their spatial organization and commercial operations. Hillier’s dual network theory provides a key framework to parse this difference, in which the foreground network and background network inscribed by the distinct urban logic of economic efficiency and socioeconomic-culture, respectively [30,42]. But this framework has long lacked a meso- and micro-scale analytical protocol to operationalize its logic for the systematic comparison of store configuration characteristics across different networks. This theory-method has prevented the dual-network perspective from being fully realized. Furthermore, the complex urban fabric of Chinese cities, characterized by the coexistence

of organic old districts and planned new districts [43], provides a distinctive for developing and testing such an analytical framework.

This study addresses this research limitation through an exploratory, multiple-case analysis designed to assess the applicability of the space syntax dual-network logic for the interpretation of street store configurations in China. Eight paired street segments across four representative cities—Tianjin, Nanjing, Zhengzhou, and Hong Kong—were selected as case studies. Using 2019 Point of Interest (POI) data, street view imagery, and field surveys, a comparison is made of store operation methods, functional diversity, and 100-m density between high-value street segments of the foreground and background network. Topological analysis is applied to distinguish these networks and to evaluate two hypotheses: (1) that foreground networks might exhibit a higher concentration of economically driven stores; and (2) that background may support a high density of stores with stronger socio-cultural embeddedness.

The primary contribution of this study is methodological. This study aims to operationalize the dual-network framework at the meso- and micro-scale and to generate contextual insights and testable propositions regarding systematic variations in street commerce, rather than universal conclusions. In particular, it makes two main contributions. First, it extends the application of the dual-network framework from macro-scale urban form to the analysis of meso- and micro-scale store patterns, thus providing a novel insight into the spatial articulation of economic and socio-cultural forces [42,44]. Second, it integrates quantitative spatial metrics with store-level attribute data to formulate a replicable analytical framework. By linking meso- and micro-scale spatial patterns to broader urban processes, the analysis advances the understanding of cities as complex adaptive systems. On a practical level, the preliminary insights derived from this exploration address identified deficits in China's commercial planning [35] and may inform strategies for optimizing store distributions to enhance economic vitality and support cultural identity, which is of particular relevance in the post-COVID-19 recovery process.

The paper is organized as follows: Section 2 reviews the dual network of space syntax and the relationship between street and store spatial configuration; Section 3 discusses the research method, including network identification and data analysis; Section 4 presents a focus on comparative outcomes; Section 5 discusses the contributions and limitations of the research; and Section 6 concludes and suggests directions for future research.

2. Research Principles

2.1. Theoretical Basis: The Dual Network Logic of Space Syntax

Space syntax constitutes a widely adopted analytical framework for the study of urban space. It facilitates the structural extraction of urban “spatial characteristics” and supports the interpretation of interactions between activity and space [45].

Rooted in natural movement theory, which proposes that street spatial configuration shapes movement flows and patterns of economic activity, Hillier identified the urban street network as comprising two integral linear structures, the “foreground network” and the “background network”. Cities in different regions around the world, whether organic or artificial, all exhibit this structural consistency. That is, they are composed of a foreground network that links city centers of all scales and a background network that is mainly located in residential areas. As Hillier describes, “The foreground network is made up of a relatively small number of longer lines, connected at their ends by open angles, and forming a super-ordinate structure within which we find the background network, made up of much larger numbers of shorter lines, which tend to intersect each other and be connected at their ends by near right angles, and form local grid like clusters.” The formation of this dual network is the imprint of economic and socio-cultural forces

upon the city. Here, the foreground network maximizes urban gridding and drives the urban micro-economy; the background network hinders the structural movement due to its specific cultural characteristics and makes the city look different. Consequently, the dual network structure reflects how micro-economic and socio-cultural forces employ the similar underlying spatial and spatial-functional laws to produce distinct effects. And in the past, urban research models have often failed to comprehensively integrate the complex interactions among spatial, economic, social, and cultural dimensions [42].

The concept of dual networks remains a notably underexplored area within the literature, having received limited scholarly attention to date. This oversight may be attributed to two principal factors. First, Hillier and his colleagues have predominantly focused on developing and refining the broader theoretical framework of space syntax, rather than elaborating significantly upon the dual-network proposition. Second, and more critically, a clear and practicable methodological pathway for implementing the dual-network concept in empirical research has yet to be established. At present, research related to dual networks has focused mainly on the significance of the binary structure of the street network at the city level. For example, the Normalised Angular Choice (NACH) and Normalised Angular Integration (NAIN) values are used to interpret and optimize urban traffic [32,33], and studies discussing urban form change are from a dual network perspective [43]. However, studies on meso- and micro-scales remain limited.

2.2. Research Perspective: Street–Store Spatial Configuration Under a Dual-Network Logic

Based on the identified research limitation, this section outlines the core analytical perspective of the study. The introduction of the dual-network logic is not intended to supersede existing network analysis methods but to serve as a targeted framework for generating specific, testable expectations regarding store configurations at the meso- and micro-scales. The study suggests that the foreground and background networks shape qualitatively different types of urban commercial life. This logic makes it possible to distinguish between street systems with different structural characteristics within the urban network, and to investigate their varying mechanisms for organizing street-level commercial activity.

Drawing on Hillier's propositions [11,46], the following operational links can be derived. The foreground network is characterized by high movement capacity, longer street segments, and strong connectivity at the city-wide scale. Its main function is to facilitate through-movement and ensure accessibility in the urban area. High connectivity and integration of streets are frequently associated with a greater potential to stimulate urban economic vitality. In contrast, the background streets constitute a fine-grained network deeply embedded within local neighborhood life, featuring shorter lengths, higher intersection density, and exhibiting high spatial integration within residential districts. Such a street would be more favorable to low-speed, high-frequency, and socio-culturally embedded daily commercial activities.

From the perspective of street stores, the core insight revealed by the dual-network logic is that foreground and background streets adhere to two distinct spatial performance logics. The advantage of foreground streets is to maximize the exposure and spatial reach of commercial activities. Meanwhile background streets optimize the capacity for accommodating daily commercial needs within a limited street frontage. This pattern can also be interpreted as a concrete manifestation of the differing influences exerted by urban economic functions versus socio-cultural functions on land use and building space along streets, differences which ultimately shape the characteristic divergence in the spatial layout patterns of street stores [27,47–49].

According to the above, this study evaluates how different network positions translate into divergent street store patterns through a comparative examination of Operation Methods, Functional Diversity, and 100-m Density between the two street network types.

3. Methods

This research selects four Chinese cities, namely Tianjin, Nanjing, Zhengzhou, and Hong Kong, as cases. With a vibrant socio-economic life and a mature civic culture, these cities provide a solid foundation for examining the link between street network structure and spatial distribution of commerce. As Hillier notes, the dual network structure is not specific to a particular urban form but is prevalent in both organically and geometrically cities, with differences primarily manifesting in their structural configuration and evolutionary pathways [42]. On the basis of this theory, this research examines the manifestations of street network structure within different urban contexts through a comparison of their distinct morphological generation mechanisms. Tianjin, Nanjing, and Zhengzhou, representing typical mainland Chinese cities, have each undergone pivotal historical phases including the founding of the People's Republic, economic reforms, and rapid urbanization. As a result within a century, their urban spatial forms have experienced several transformations. This process has resulted in street networks characterized: they retain sections of old urban fabric with typical organic network features, while also incorporating the geometric street layouts of new districts formed through large-scale construction since the reform era. This overlap results in an ideal situation for comparison regarding the coexistence and interplay of different structures within the same city's ambit. Hong Kong's modern urban form, shaped by strong topographic constraints and a market-driven development mechanism, demonstrates a relatively continuous and stable evolutionary trajectory. The street network is still mostly organically generated. The city thus serves as a useful reference for studying street network structures that formed along a divergent development path.

This study employs the dual network logic of space syntax to evaluate the spatial configuration of street stores across eight street segments in four Chinese cities by combining topological analysis with empirical store data. The methodological framework includes three steps: (1) the identification of the street network, (2) the selection of street segments and data collection, and (3) comparative analysis of store configurations. Each step is described below, with illustrative examples to ensure methodological transparency and replicability.

Data from the street stores is collected primarily from point of interest (POI) data and street view images, supplemented by field surveys. To mitigate the impact of the COVID-19 on street stores, data from 2019 were utilized, as a significant number of street businesses closed after 2020, and post-pandemic short-term data no longer reflect normal commercial patterns.

3.1. Street Network Identification

Street networks of Tianjin, Nanjing, Zhengzhou, and Hong Kong were modelled using 2019 geospatial data from Baidu Maps (API version), Google Maps (API version), and OpenStreetMap (OSM) (data release version). Data consistency was ensured by cross-validating alignments and resolving discrepancies. Networks were digitized into axial maps—linear representing streets—and processed in DepthMapX (version 0.8.0) for space syntax analysis.

The background and foreground street networks were distinguished using Normalised Angular Choice (NACH) and patchwork pattern analysis. NACH, which measures street selectivity in the context of global spatial depth, was used to identify foreground networks characterized by high traffic potential. This measure effectively reveals the internal structure

of urban morphology and facilitates comparative analysis of street network configurations across different cities or different areas within the same city [31]. Hillier and Yang noted that NACH maps at a radius of 1.4 km exhibit greater comparability, which should contribute to the further comprehension of the relationship between local organization and global structure across different cities [30]. The foreground network in this study is defined as comprising street segments falling within the top 20% of NACH values for each respective city [30,50]. The NACH value is calculated using the following formula:

$$NACH = \log(\text{value}(\text{"T1024 Choice"}) + 1) / \log(\text{value}(\text{"T1024 Total Depth"}) + 3) \quad (1)$$

Choice (CH) represents the potential for through-movement within the spatial system. Total Angular Depth (TD) is defined as the cumulative sum of the shortest angular path depths from a given segment to all other segments in the system.

Conversely, the patchwork pattern represents metric distance in the urban structure and can be used to identify the background network. This method captures local spatial features and effectively identifies pedestrian-friendly areas within a defined radius [31]. For this analysis, a 1000 m radius is used to calculate the metric distance mean depth (MD). The background network is identified through an analysis of the metric distance MD of streets. This network is characterized as a series of contiguous spatial units, within each of which streets exhibit high homogeneity in local accessibility values, whereas significant differences exist between distinct units. These homogeneous units constitute the spatial substructures that support routine, localized activities within the city [31]. The MD is calculated as follows:

$$MD = TD / NC \quad (2)$$

Total Angular Depth (TD) represents the cumulative sum of the shortest angular paths from a given segment to all other segments. Node Count (NC) denotes the total number of segments traversed when connecting the current segment to all others.

The delineation of the background network followed a quantitative protocol. First, segments were categorized into the same preliminary cluster if their MD values fell within $\pm 10\%$ of the local cluster mean. Second, a definitive boundary between adjacent clusters was established where contiguous segments exhibited an MD difference exceeding 15% of the global MD range across the city. Following this clustering, the street segments with MD values within the lowest range were selected from each identified background cluster as high-value case study samples.

3.2. Sample Selection and Data Collection

In light of the exploratory nature of this research and the analytical depth required, a purposive small-sample case study design was adopted. This methodological approach is especially appropriate for theory construction and mechanism investigation within real-world contexts.

To facilitate comparative analysis, street stores were sampled from eight typical street segments in four typical cities: four are high-value segments in the foreground network, and four in the background network. The selection followed three criteria: (1) the micro-economic and socio-cultural environment should be stable and an old urban area preferred; (2) typicality within network types, excluding specialized urban areas with special significance, such as CBDs and historic districts; and (3) spatial proximity between foreground and background segments (with the distance to the nearest point constrained to within 2 km) within the same city to control for population and consumption-related factors [51].

Based on the analysis of NACH and MD values, and taking into account data availability, the following eight street segments were selected: Kunwei Road in Tianjin (the segment

from Zhongshan Road to Jinzhonghe Street; a bidirectional six-lane arterial road with mixed land use predominantly for residential, educational, and commercial services; average NACH: 1.51), South Zhongshan Road in Nanjing (the segment from the East Zhongshan Road to Jianye Road; a bidirectional six-lane arterial road characterized by a mix of commercial and residential functions; average NACH: 1.56), Longhai Road in Zhengzhou (the segment from Huashan Road to Tongbai South Road; a bidirectional six-lane arterial road primarily supporting residential and office functions, with ancillary healthcare facilities; average NACH: 1.42), and Kwun Tong Road in Hong Kong (the segment from Chong Yip Street to Tseung Kwan O Road; a five-lane urban arterial road with mixed commercial and residential land use; average NACH: 1.59). The corresponding high-value segments of the background networks are: Luwei Road in Tianjin (the segment from Wuma Road to Zhongshan Road; a one-way, single-lane local street primarily serving residential areas, with intermittent mixing of commercial and educational/service facilities; average MD: 606), Chaotiangong West Street in Nanjing (the segment from Luolang Road to Mochou Road; a bidirectional two-lane local street dominated by residential functions; average MD: 588), Guomianchang Street in Zhengzhou (the segment from Mianfang West Road to Jianshe West Road; a bidirectional two-lane local street with a primarily residential character; average MD: 607), and Ngau Tau Kok Street in Hong Kong (the segment from the Kung Lok Road to Hong Ning Road; a one-way, two-lane local street where commercial functions are primary, mixed with residential uses; average MD: 612) (Figures 1 and 2).

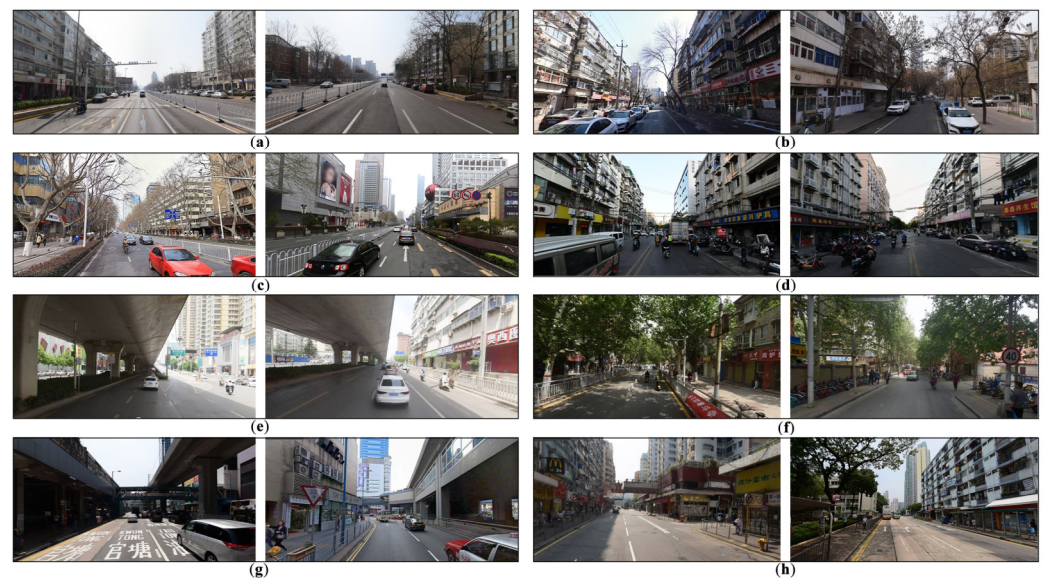


Figure 1. Street view imagery of the typical street segments. (a) Tianjin Kunwei Road; (b) Tianjin Luwei Road. (c) Nanjing South Zhongshan Road; (d) Nanjing Chaotiangong West Street. (e) Zhengzhou Longhai Road; (f) Zhengzhou Guomianchang Street. (g) Hong Kong Kwun Tong Road; (h) Hong Kong Ngau Tau Kok Street.

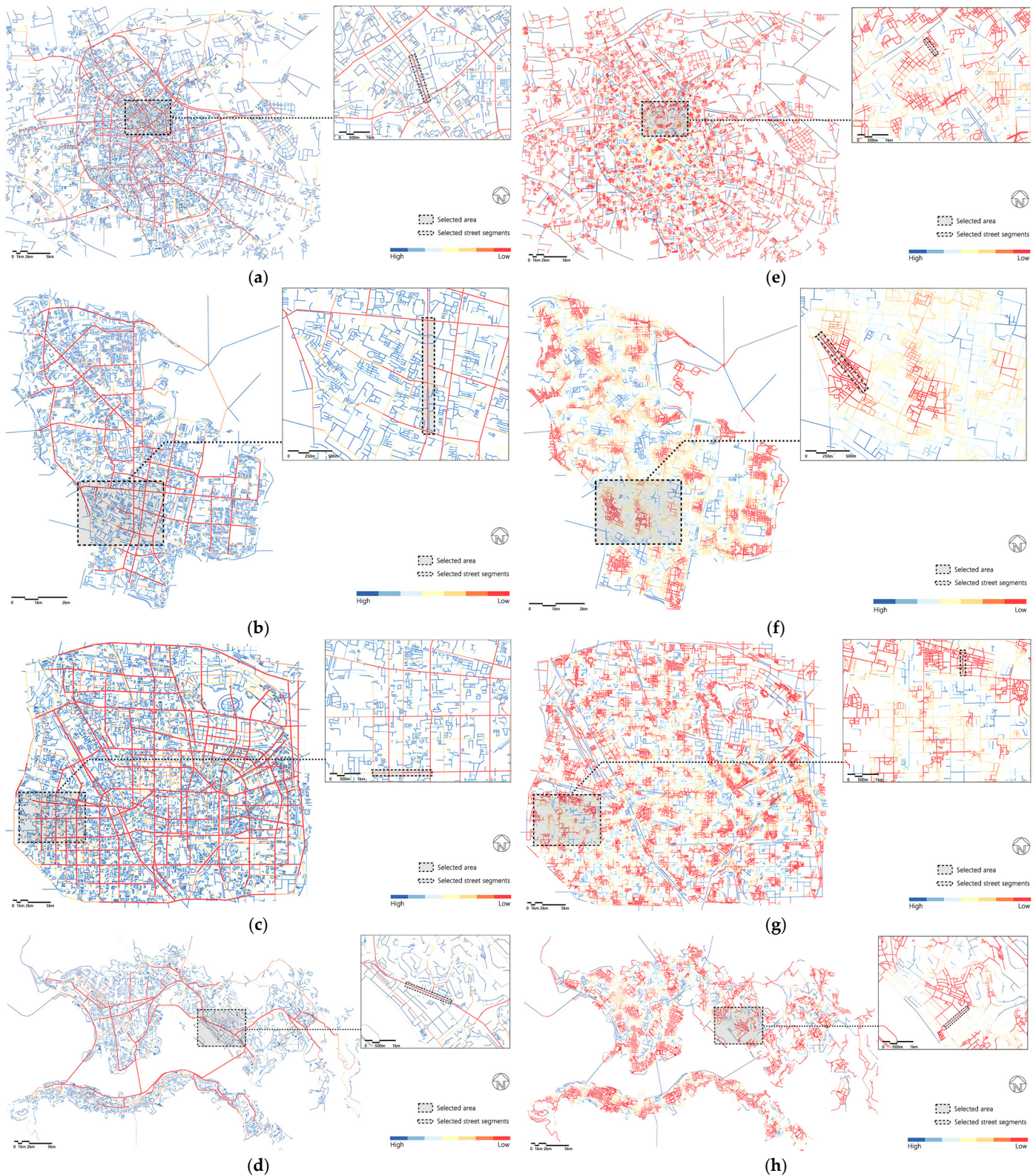


Figure 2. (a) NACH analysis of the Tianjin street network and Kunwei Road (the segment from Zhongshan Road to Jinzhonghe Street); (b) NACH analysis of the Nanjing street network and South Zhongshan Road (the segment from the East Zhongshan Road to Jianye Road); (c) NACH analysis of the Zhengzhou street network and Longhai Road (the segment from Huashan Road to Tongbai South Road); (d) NACH analysis of the Hong Kong street network and Kwun Tong Road (the segment from Chong Yip Street to Tseung Kwan O Road). (e) the patchwork patterns of the Tianjin street network and Luwei Road (the segment from Wuma Road to Zhongshan Road); (f) the patchwork patterns

of the Nanjing street network and Chaotiangong West Street (the segment from Luolang Road to Mochou Road); (g) the patchwork patterns of the Zhengzhou street network and Guomianchang Street (the segment from Mianfang West Road to Jianshe West Road); (h) the patchwork patterns of the Hong Kong street network and Ngau Tau Kok Street (the segment from the Kung Lok Road to Hong Ning Road).

3.3. Comparative Analysis of the Spatial Configuration of Street Stores

Store-level data were processed through a standardized pipeline: (1) filtering Points of Interest (POIs) and geocoding them to street segments; (2) manually verifying and coding attributes, such as operation method and function category, using Street View imagery and chain brand directories; and (3) computing effective length L .

3.3.1. Measurement and Classification of Operation Methods

Stores were classified as sole or chain based on POI and field survey data. The sole store business model relies on individual or small-scale operators to independently handle management, investments and personnel. Operators make business decisions based on their own preferences and control the management characteristics and development orientation. Sole stores can extensively infiltrate various consumption localities and flexibly meet the needs of consumers and are personalized and flexible [52]. In contrast, a chain store is a management and organizational form in which a number of stores sell similar products or services to achieve economies of scale through standardized operation under unified guidance. Chain stores are characterized by standardized images and approximations of products and services.

The proportions of these two operation methods were calculated and compared across the high-value street segments of the foreground and background networks. Proportions were used to assess the degree of economic standardization versus local adaptability.

3.3.2. Calculation of Functional Diversity Metrics

Stores were grouped into nine categories (Table 1)—prepared food, commodity sales, accommodation, financial, living, car, recreation, education, and medical—tailored to Chinese contexts [53].

Table 1. Classification of street stores.

Type of Store	Store Function
Prepared food services	Restaurants, fast food restaurants, snack bars, coffee shops, cafes, etc.
Commodity sales	Shopping malls, supermarkets, vegetable markets, convenience stores, small stores, etc.
Accommodation services	Hotels, inns, and other facilities that mainly provide medium and short-term accommodation services, excluding apartments
Financial services	Banking business halls, insurance stores, etc., excluding the entrances of financial office buildings on the ground floor of the streets, etc.
Living services	Barbershops, dry cleaners, beauty parlours, telecommunication service stores, etc.
Car services	Gas stations and establishments providing car washes, repairs, maintenance and other services.
Recreation and fitness	Cinemas, bars, KTVs, swimming pools, game rooms, etc., excluding outdoor spaces such as sports fields
Education and training services	All kinds of training services, excluding facilities such as schools, kindergartens, and culture palaces
Medical services	Clinics, pharmacies, medical device stores, etc., excluding hospitals at all levels

The Shannon–Wiener index (H'), a foundational metric for evaluating richness and evenness in ecological and spatial studies, was employed [54,55]. It is calculated as follows:

$$H = -\sum(\pi_i \times \ln(\pi_i)) \quad (3)$$

where H represents the Shannon–Wiener diversity index, π_i represents the relative richness of the store category, $\sum$ represents the sum of all store categories, and $\ln$ represents the natural logarithm.

To facilitate an intuitive interpretation—particularly for urban planning applications—the index was subsequently transformed into the Effective Number of Types (ENT), expressed as $ENT = \exp(H')$ [54,55]. This metric represents the number of equally abundant categories required to produce the observed level of diversity, providing a linear and directly interpretable measure. In this analysis, ENT values are primarily reported to articulate the ‘functional capacity’ of street networks, while H' is retained as the underlying theoretical measure.

3.3.3. Measurement Protocol and Calculation of 100-Meter Density

100-m street store density is the average number of stores per 100 m of continuous store-accessible frontage along a street, excluding road intersections, neighborhood entrances and exits, construction sites, and other areas where commercial use is restricted by urban regulations. A 100-m density reflects the distribution density of stores on the street, and the corresponding formula is as follows:

$$D = 100 \times Q/L \quad (4)$$

where D is the 100-m density of stores, Q is the total number of stores in the street segment, and L is the effective street frontage length of the selected street segment.

- (1) **Operational Definition and Coding Protocol:** the effective street frontage length (L) is operationally defined as the sum of continuous lengths of building façade facing the street segment that is available for hosting stores. For the purpose of obtaining objective and reproducible measurements, all data was collected from high-resolution 2019 street view imagery (source: Baidu Map Street View) by its built-in distance measurement tool. The specific determination of length adheres to a pre-established standardized coding protocol (Table 2), which provides precise geometric and functional definitions for various non-commercial interfaces to be excluded.

Table 2. Coding protocol for measuring effective street frontage length.

Exclusion Category	Operational Definition (Image-Based)	Buffer Distance/Rule	Rationale
Road Intersection Influence Zone	Measured from the intersection point of the extended curb lines	Within 10 m	This zone experiences disrupted pedestrian flow and visual continuity, resulting in lower commercial value.
Non-Commercial Primary Access Points	Independent openings without commercial signage, intended solely for vehicle or pedestrian entry/exit.	The opening itself and 5 m on each side	Functionally unsuitable for commercial activity.
Continuous Non-Commercial Facades	Uninterrupted solid walls, perimeter walls, or permanent barriers without shop doors, display windows, or signage.	Entire length of the facade	Physically incapable of serving as a commercial interface.

- (2) **Inter-Rater Reliability Assessment Design:** To assess the consistency of the coding protocol and measurement procedure, two researchers independently measured all eight street segments according to the specifications outlined in Table 2. The reliability of the measurements was assessed through the intraclass correlation coefficient (ICC) for absolute agreement (model ICC (3, 1)). The result of the specific calculation is given in Section 4.3.
- (3) **Sensitivity Analysis Design:** Two sensitivity analyses were designed and conducted to test the robustness to key measurement parameter settings. First, the intersection buffer distance was adjusted to 5 m (lenient) and 15 m (strict). Second, street frontage within 3 m of other potential openings not defined in Table 2 such as minor passages and alley entrances was excluded. The numerical calculations under these various rule sets contribute to the density found in Section 4.3, which helps assess how robust the patterns are.

4. Results

This section shows the results of a comparative analysis of street store configurations across the eight segments within the foreground and background networks of four Chinese cities. The findings presented in three subsections: operation methods, functional diversity, and 100-m density. For each metric, results are quantified, subjected to statistical testing, and visualized in order to clarify systematic differences in the spatial configuration of the street store as constituted by the dual network logic of space syntax.

4.1. Operation Methods

Given the small, purposive sample, the analysis relies on cross-case pattern matching rather than inferential statistics. Two principal patterns emerge from the operation methods data (Table 3, Figures 3 and 4).

Table 3. Quantity and proportion of street store.

City	Network Type	Segment	Total Number of Stores	Type of Store	Quantity	Proportion
Tianjin	High-value street segment of foreground network	Kunwei Road	89	Sole stores	32	36.0%
	High-value street segment of background network	Luwei Road		Chain stores	57	64.0%
Nanjing	High-value street segment of foreground network	South Zhongshan Road	102	Sole stores	35	74.5%
	High-value street segment of background network	Chaotiangong West Street		Chain stores	12	25.5%
Zhengzhou	High-value street segment of foreground network	Longhai Road	152	Sole stores	70	68.6%
	High-value street segment of background network	Guomianchang Street		Chain stores	32	31.4%
Hong Kong	High-value street segment of foreground network	Longhai Road	88	Sole stores	98	64.5%
	High-value street segment of background network	Guomianchang Street		Chain stores	54	35.5%
Hong Kong	High-value street segment of foreground network	Longhai Road	104	Sole stores	41	46.6%
	High-value street segment of background network	Guomianchang Street		Chain stores	47	53.4%
Hong Kong	High-value street segment of foreground network	Kwun Tong Road	59	Sole stores	77	74.0%
	High-value street segment of background network	Ngau Tau Kok Road		Chain stores	27	26.0%
Hong Kong	High-value street segment of foreground network	Kwun Tong Road	59	Sole stores	31	52.5%
	High-value street segment of background network	Ngau Tau Kok Road		Chain stores	28	47.5%

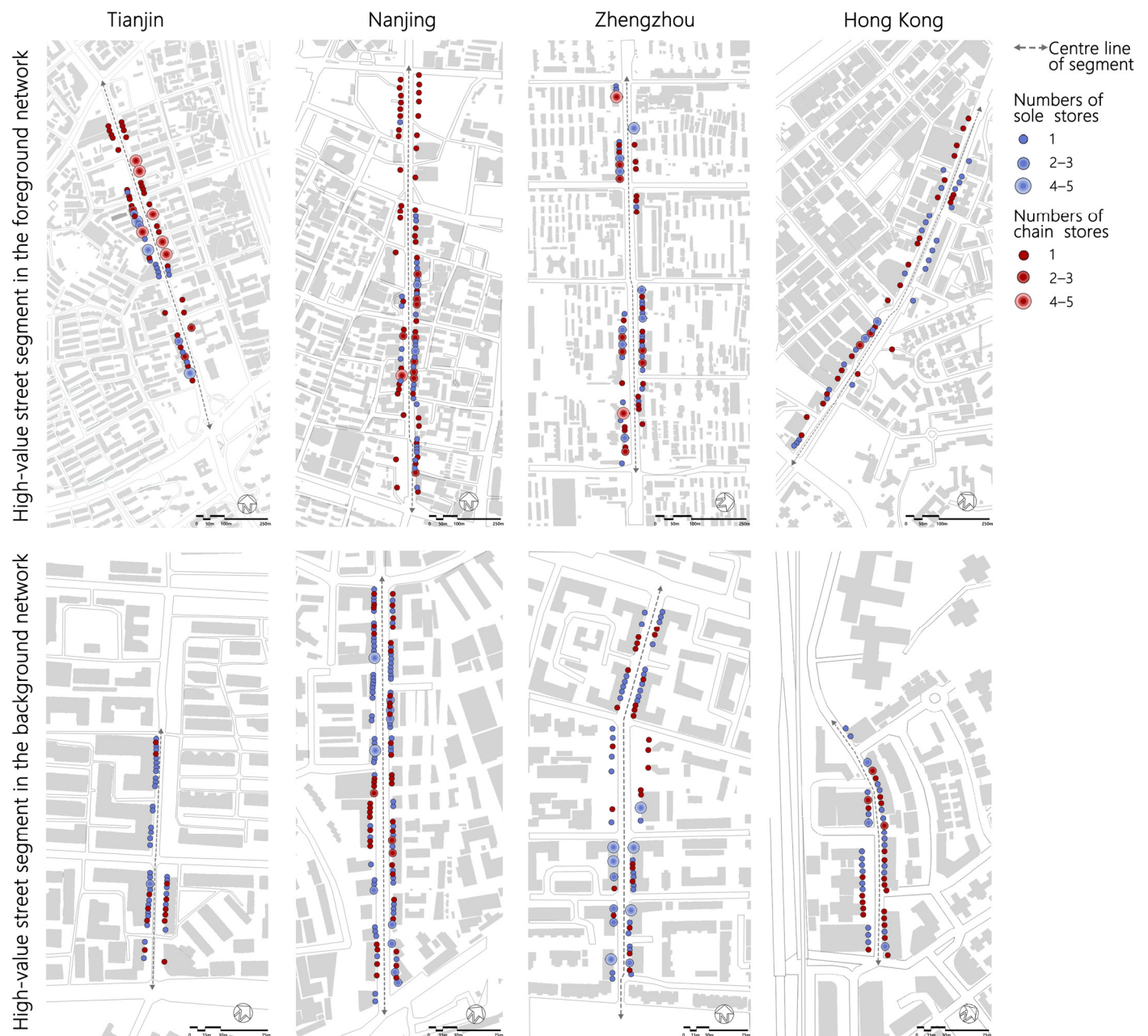


Figure 3. Distribution of street stores.

Analysis of the operational data reveals two distinct commercial patterns corresponding to network type. First, within the high-value segments of the background network, sole stores consistently constituted a larger proportion than chain stores across the cities. This dominance was particularly pronounced in Tianjin (74.5% vs. 25.5%) and Zhengzhou (74.0% vs. 26.0%). Hong Kong presented an exception, with a near-equivalent distribution (52.5% vs. 47.5%). Second, within the same city, the proportion of chain stores in the high-value segment of the foreground network was either higher than or comparable to that in its paired background network segment. This pattern suggests that chain stores are less sensitive to the classification of street networks than sole stores. This differential sensitivity may be attributed to the finding that consumer patronage of chain stores is consistently influenced by brand loyalty [56,57].

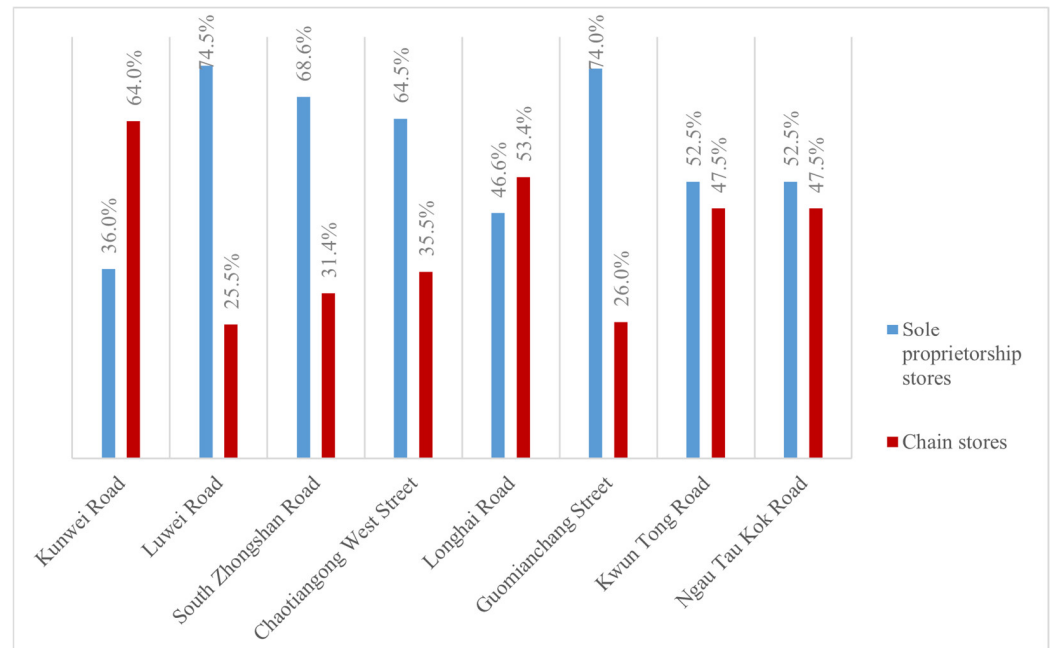


Figure 4. Bar chart of the comparison of street store operation methods.

To quantify the within-city contrast, the difference in the proportion between chain stores and sole proprietorships within the high-value segments of the background network was calculated for each city (Table 3). A positive value indicates a higher proportion of sole stores in the background segment. The differences are as follows: Tianjin +49.0%, Nanjing +29.0%, Zhengzhou +48.0%, and Hong Kong +5.0%. Among the three mainland Chinese city pairs, the background network shows a clear advantage for sole stores. The exceptional case of Hong Kong highlights the potential influence of contextual factors beyond network type.

4.2. Functional Diversity

Functional diversity, quantified via the Shannon–Wiener index (H') and its transformation into the Effective Number of Types (ENT), exhibited systematic variation between network types. High-value segments in foreground networks demonstrated consistently higher diversity than their counterparts in background networks (Table 4, Figure 5).

Table 4. Comparison of the operation methods of street stores.

Service Type	Tianjin		Nanjing		Zhengzhou		Hong Kong	
	Kunwei Road	Luwei Road	South Zhongshan Road	Chaotiangong West Street	Longhai Road	Guomianchang Street	Kwun Tong Road	Ngau Tau Kok Road
Prepared food services	15	29	26	39	25	43	6	19
Commodity sales	38	9	39	67	32	38	26	29
Accommodation services	1	0	8	4	2	0	0	0
Financial services	4	1	7	2	2	0	6	6
Living services	18	8	14	24	17	14	11	3
Car services	2	0	1	1	1	2	3	0
Recreation and fitness	1	0	0	6	2	0	2	1
Education and training services	4	0	1	0	4	0	2	0
Medical services	6	0	6	9	3	7	3	1

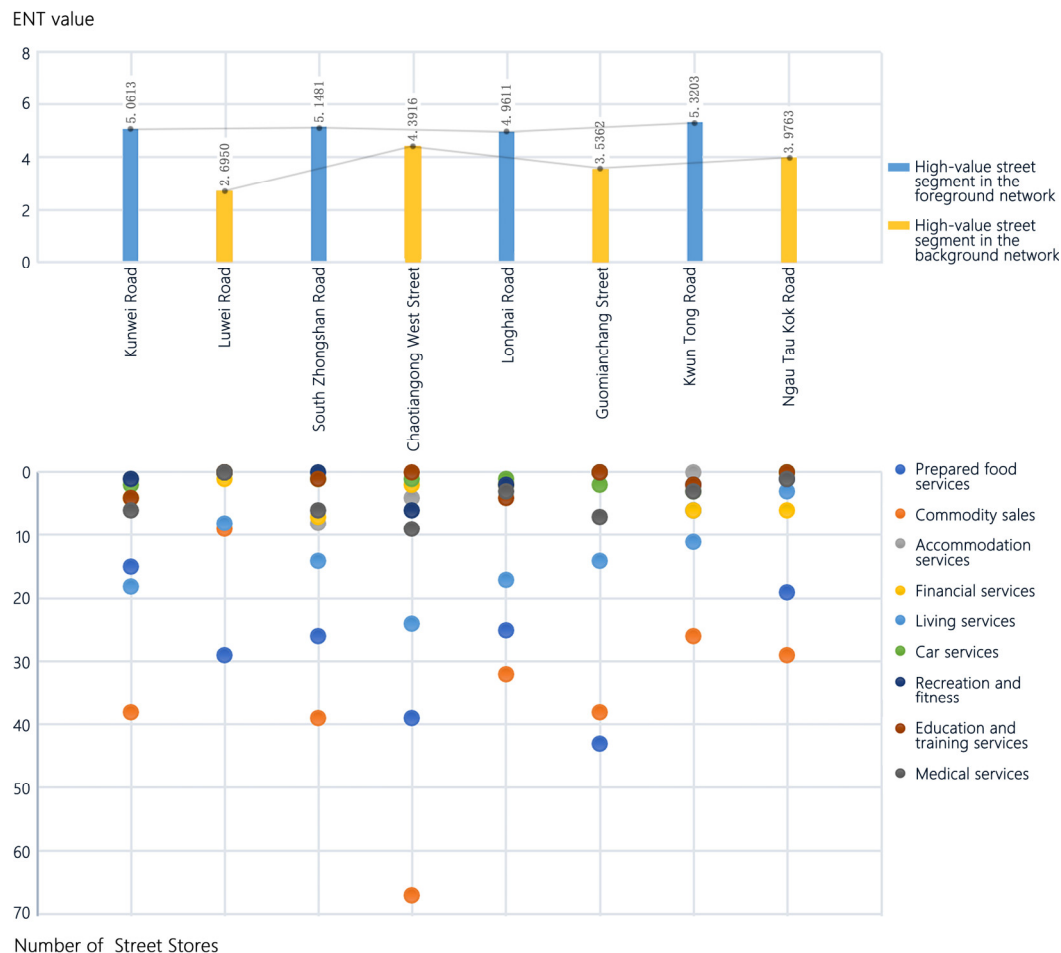


Figure 5. Comparison of the Effective Number of Types and the quantity of street stores.

The ENT metric offers a clear and interpretable measure. As derived from Table 4 and illustrated in Figure 5, the mean ENT for foreground network segments was 5.12 (range: 4.96–5.32), compared to 3.65 (range: 2.70–4.39) for background network segments. This indicates that the functional mix on foreground streets is equivalent to having approximately five distinct and evenly distributed store types, a value consistently higher than the approximate 3.5 types characteristic of background streets. The underlying H' values followed the same pattern (foreground mean $H' = 1.63$; background mean $H' = 1.25$), corroborating the ENT findings.

The within-city difference in ENT (Foreground minus Background) further illustrates this pattern: Tianjin, +2.36; Nanjing, +0.76; Zhengzhou, +1.42; and Hong Kong, +1.34. The direction of the difference was consistent across all four city pairs (4/4), with the foreground network exhibiting higher ENT values. The magnitude of the advantage varied, ranging from 0.69 to 2.41 effective categories.

The distribution of store categories further underscored this disparity. High-value street segments of the foreground networks featured a near-complete coverage of all nine defined store types. Conversely, store in the background networks were heavily skewed toward daily categories servicing daily needs.

4.3. 100-m Density

According to the analysis, the 100-m density store in street segments of the background network is more than its counterpart in the street segments of the foreground network, consistently (Table 5). All four city pairs proved the same relationship. Specifically, the median density for street segments of the foreground network is 5.67 stores/100 m, compared to

16.59 stores/100 m for street segments of the background network. The paired ratios yield a geometric mean of 2.59, which indicates that the intensity of retail agglomeration of street segments of the background network is on average around 2.6 times greater than that of foreground network.

Table 5. 100-m density of street stores.

City	Type	Name of Street Segment	Total Number of Stores	Effective Street Frontage Length (m)	100-m Density (Stores/100 m)
Tianjin	High-value street segment of foreground network	Kunwei Road	89	1112	8.01
	High-value street segment of background network	Luwei Road	47	418	11.25
Nanjing	High-value street segment of foreground network	South Zhongshan Road	102	2019	5.05
	High-value street segment of background network	Chaotiangong West Street	152	906	16.78
Zhengzhou	High-value street segment of foreground network	Longhai Road	88	1400	6.29
	High-value street segment of background network	Guomianchang Street	104	615	16.92
Hong Kong	High-value street segment of foreground network	Kwun Tong Road	59	1365	4.32
	High-value street segment of background network	Ngau Tau Kok Road	59	359	16.40

The background-to-foreground density ratio was greater than 1 for all four city pairs (4/4), confirming a consistent pattern of higher store density in background networks. The individual city pair ratios were: Tianjin (1.40), Nanjing (3.32), Zhengzhou (2.69), and Hong Kong (3.80). The consistency in direction across cases is notable, while the variation in ratio magnitude reflects contextual modulation of the effect.

The reliability for measuring effective street frontage length was excellent. The intra-class correlation coefficient (ICC) for absolute agreement between two independent coders was $ICC(3, 1) = 0.96$ (95% CI: 0.93, 0.99) [58].

Sensitivity analyses further support the stability of this density differential (Table 6). The pattern of higher density in the background network persisted under all alternative measurement rules. Across all four city pairs, the direction of the difference remained consistent (4/4), and the geometric mean of the paired ratios (calculated from each city pair) fluctuated within a narrow range of 2.56 to 2.60. A paired-samples sign test confirms the perfect directional consistency, although its *p*-value should be interpreted with caution given the very small sample size. Nevertheless, the complete directional consistency and the narrow dispersion of the ratio magnitudes indicate that the observed pattern is not sensitive to reasonable variations in measurement rules.

Table 6. Sensitivity analysis: 100-m density under different measurement rules.

Analysis Scenario	Foreground Network Median	Background Network Median	Paired Ratio (Geometric Mean)
Baseline Rule (10 m buffer)	5.67	16.59	2.59
Lenient Rule (5 m buffer)	5.68	15.61	2.60
Strict Rule (15 m buffer)	6.61	18.43	2.56

An analysis of the distribution of storefronts by width offers additional qualitative evidence in support of the quantitative results (Figure 6). Street segments of foreground network exhibit a mix of narrow (4–6 m) and wide (>10 m) storefronts. In contrast, street segments of background network are predominantly composed of uniformly narrow-frontage stores.

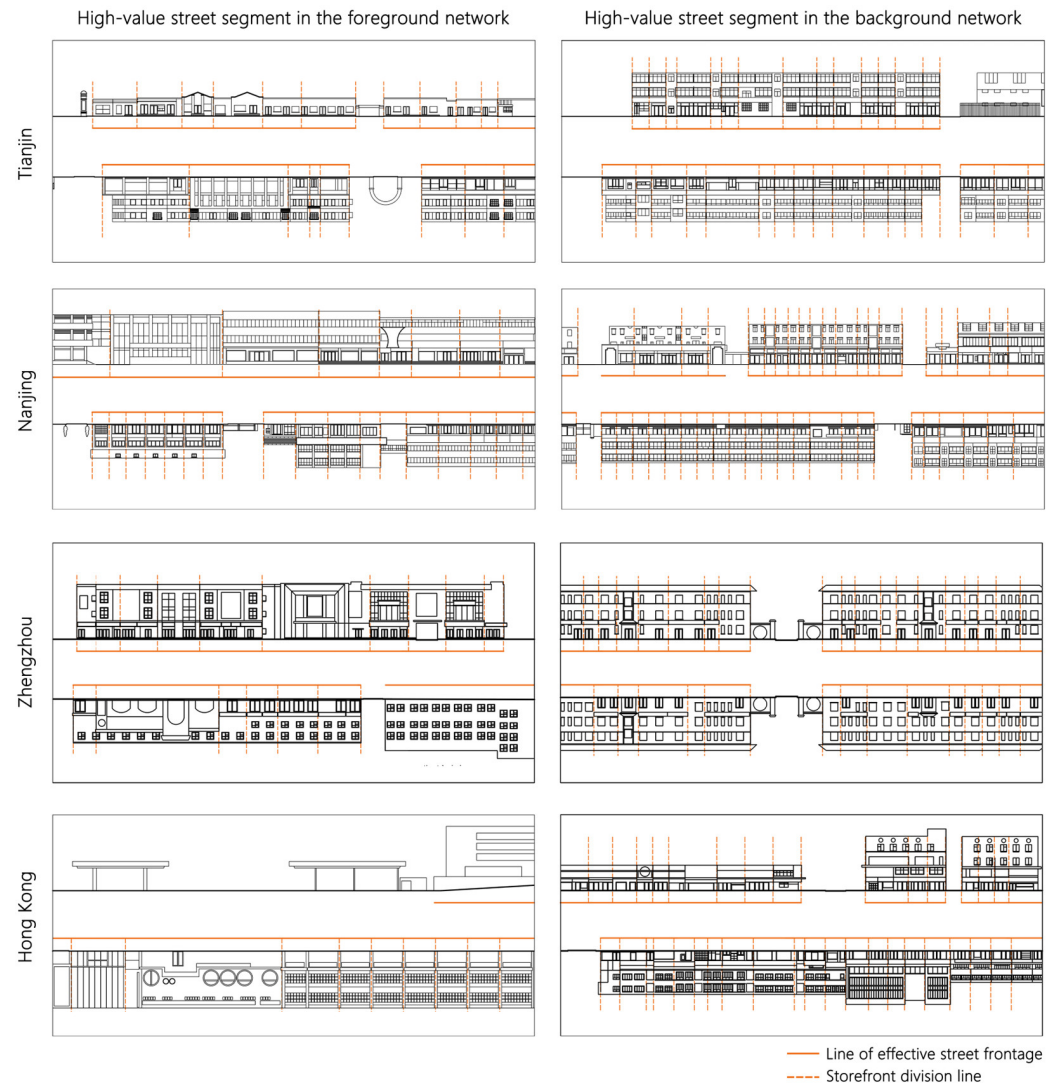


Figure 6. Facades of street stores.

5. Discussion

This exploratory multiple-case study examines the applicability of the space syntax dual-network logic in explaining the spatial configuration differences in street stores in Chinese cities. The analysis focused on operation methods, functional diversity, and 100-m density. The findings showed systematic variations, which align with Hillier's theoretical framework concerning cities as spatial products of economic and cultural processes [42]. It is essential to emphasize that the aim of this study is not to draw universal conclusions, but rather, through limited cases, to operationalize the dual-network theory at the meso- and micro-scales, as well as to propose causal hypotheses and mechanistic conjectures for future testing.

5.1. Operation Methods: The Spatial Imprint of Standardized Economy and Local Socio-Culture

The analysis revealed a distinct pattern in operation methods: As directional evidence, high-value segments in the foreground network possessed a modest advantage in the prevalence of chain stores, while those in the background network were predominantly occupied by sole stores. This observed spatial correlation aligns with Hillier's proposition that foreground networks attract activities that benefit from broad accessibility and economies of scale [59]. Within the analytical framework of this study, chain stores are employed as a proxy for a standardized, efficiency-seeking economic logic—a logic reliant on brand loyalty and replicable operational model. Conversely, sole stores are treated as a potential indicator of locally adaptive, small-scale operations characterized by greater flexibility in meeting neighborhood-specific demands.

The pronounced prevalence of sole stores in background networks is consistent with the theoretical expectation that such locally integrated, fine-grained environments are more conducive to this business form, potentially serving as an indicator of deeper socio-cultural embeddedness [52]. Conversely, the spatial distribution of chain stores appeared less sensitive to the foreground/background network classification than that of sole proprietorships, a characteristic potentially attributable to the greater influence of brand loyalty and standardized location strategies that transcend local network types [60].

Consequently, while the observed dichotomy aligns with the core premise of the dual-network theory and questions macro-scale studies that overlook network-specific effects [13], the Hong Kong case underscores that the chain/sole proprietorship dichotomy serves as an imperfect proxy. The distribution of street stores may be shaped by a broader constellation of factors than those explained solely by the foreground/background network logic derived from space syntax. Other influential dimensions could include distinctive urban morphological conditions, as exemplified by Hong Kong's notably compact and high-density form, alongside non-spatial variables beyond the scope of this analysis—such as land-value gradients [61,62], brand saturation dynamics [21,63], or local regulatory environments [64,65]. It is crucial to avoid conflating the observed spatial sorting with a direct causal mechanism. This interpretation is predicated on the conceptual link between store type and underlying socio-economic logic; direct measures of operational standardization or socio-cultural embeddedness fall beyond the scope of this spatial-configurational analysis. Future research should therefore integrate data on commercial rents, pedestrian volume flows, or business-owner surveys to disentangle these overlapping influences.

5.2. Functional Diversity: The Tension Between Universal Supply and Local Demand

The observed pattern indicates that the functional diversity of street segments of the foreground network was higher than that of comparable street segments in the background network, with their business formats covering a broader range from retail and catering to finance and leisure. This aligns with the theory of natural movement [66], which posits that streets with high connectivity, serving as the primary skeleton of urban activity, attract diverse functions to meet general urban needs. On the other hand, street segments of the background network are more associated with daily activities, reflecting socio-cultural characteristics rather than economic diffusion.

These findings validate and refine prior research by Scoppa and Peponis linking street connectivity to commercial variety, by further associating diversity with network type [41]. They suggest that the concept of “diversity” itself may encompass different dimensions: the foreground network facilitates a comprehensive diversity serving mobile urban populations, while the background network exhibits a targeted diversity focused on daily necessities. The lower diversity in street segments of the background network contrasts with some Western studies where residential areas often exhibit mixed uses [6].

5.3. 100-m Density: The Response to Spatial Efficiency and Social Intensity

A consistent finding across all city pairs is that street segments of the background network possessed a consistently greater store density and a more restricted storefront than street segments of the foreground network. This robust pattern offers strong directional support for Hillier's view of the background network as socio-culturally dense, enabling small-scale stores to thrive in tight clusters [42]. As Jacobs stated, the high-density, fine-grained shop layout creates local identities, allows flexibility and energizes street life and local economy resiliency [7].

The wider frontage and lower density observed in the foreground network may reflect a pursuit of economic output efficiency. This is suitable for business types such as bank branches and big restaurants with higher space and visibility requirements [28]. Conversely, the high density in the background network can be viewed as the result of the competitive allocation of limited street frontage among numerous local operators, reflecting survival strategies based on social networks and niche markets. This fundamental density difference challenges macro-scale models that posit a simple positive correlation between commercial agglomeration intensity and street centrality [26], highlighting that, at meso- and micro-scales, social-cultural density and economic circulation efficiency may follow distinct spatial organizational logics.

This fundamental density difference highlights that commercial intensity follows distinct logics at the meso-scale. Nevertheless, the causal pathways remain to be fully elucidated.

5.4. Research Boundaries and Theoretical Advancement

The primary contribution of this study is methodological: operationalizing the dual-network framework to compare street-store configurations. Its core strength lies in revealing consistent correlative patterns that serve as directional evidence for testable hypotheses. The study deliberately focuses on the spatial-configurational imprint of urban processes.

First, while this study establishes the explanatory relevance of spatial configuration variables. Future research that incorporates data on land value, flow of pedestrian and policy texts for multivariable modelling and triangulation could more precisely isolate the independent effect of spatial structure itself. To build a more comprehensive explanatory model, future work must directly integrate key socio-economic and built-environment variables—such as the mix of adjacent building uses, local purchasing power, and pedestrian flow volumes. Incorporating data from land use maps, mobile phone signaling, or consumer surveys would help disentangle the effects of these factors from pure spatial structure and model the multi-causal interactions that shape street-level economies.

Second, the measurement of socio-cultural embeddedness is a theoretical inference from spatial-economic morphology. A more direct capture of this construct would require future surveys targeting proprietors' local networks, customer bases, and business practices. By isolating spatial variables to reveal their patterning effect, it inherently brackets other concurrent forces. These include economic (e.g., land values, local purchasing power), institutional (e.g., zoning, licensing), socio-cultural, and immediate built-environment factors that shape demand. Thus, the observed spatial patterns should be interpreted as outcomes viewed through a configurational lens within a multi-causal field. Future mixed-methods work integrating this spatial framework with data on pedestrian flows or demographics would help disentangle these overlapping influences.

Finally, the case selection and static cross-sectional data (2019) in this study provide an empirical entry point for the theoretical framework. This static lens extends to our operational metrics. The findings therefore require testing in a wider range of urban contexts and dynamic time series that can track both spatial evolution and business lifeways.

The transformation of the commercial ecology in the post-pandemic era, in particular, constitutes a highly relevant avenue for such future longitudinal research.

6. Conclusions

This study, through an analysis of eight street segments across four Chinese cities, preliminarily validates the heuristic value of the space syntax dual-network logic as a framework for interpreting the different spatial configurations of street stores. The comparative analysis indicated that the foreground and background networks give rise to distinct store configurations, corresponding to different economic and socio-cultural roles at meso- and micro-scales.

At the theoretical level, the main contribution of this research is the methodological bridge. It transforms a macro-scale urban morphological theory into a workable analytical method for systematically comparing meso- and micro-scale commercial space logic. By combining store data with topological measures, it provides a preliminary, measurable operationalization of the “foreground-background” dichotomy, offering a replicable pathway for future research to investigate how economic and socio-cultural processes are concretely inscribed onto different types of street space.

At the practical level, this study provides a differentiated strategic perspective for the planning context of China’s urban commercial space, which an emphasis on refined governance. Planning interventions should move beyond the singular goal of “commercial prosperity” to respect and reinforce the inherent logic of different street networks. For the foreground network, planning should aim to shape efficient and composite urban service corridors. While ensuring traffic efficiency, urban design guidelines and land policy tools can be used to avoid excessive homogenization and standardization of commercial functions. For the background network, the primary planning objective should be to conserve and cultivate the micro-resilience of the community commercial ecology. This requires safeguarding fine-grained street networks and appropriate street stores in regulatory plans and implementing support policies to lower the entry barriers for sole proprietorships.

This study essentially initiates a research agenda. Future work should deepen along three directions: first, expanding the empirical base by incorporating more variables for control and modeling, such as quantitative data on the socio-economic and built-environment context (e.g., land use, pedestrian flows, local purchasing power) to test and refine the dual-network framework under more complex, real-world conditions; second, deepening mechanistic research by employing mixed methods to directly measure key concepts like socio-cultural embeddedness; and third, extending dynamic and comparative perspectives to examine spatiotemporal evolution and conduct cross-cultural comparisons, thereby testing and developing the boundary conditions and generalizability of the dual-network explanatory framework. Ultimately, understanding and reconciling these deep-seated logics inherent in different street networks is foundational to creating urban commercial environments that integrate economic vitality, social inclusion, and cultural identity.

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