THE SPATIAL LAYOUT OF BANK LOCATIONS AND INDUSTRIAL CLUSTERS IN THE KANTO REGION IN 1905: A QUANTITATIVE ANALYSIS USING VORONOI DIAGRAMS AND MS-SSIM

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Abstract

This study aims to elucidate the spatial relationships between banks—which functioned as financial pumps circulating capital into various industries—and administrative boundaries or natural geographic features, and to examine how their distribution related to the spatial structure of industrial clusters. The authors analysed the development of industrial clusters in Japan at the beginning of the 20th century, indicating that the locations of early financial institutions served as important indicators reflecting the realities of regional economic activities and their networks.

Keywords: clusters, industrial, space, development, banking, urban, talent, governance, management, Japan, innovation, emotion, transformation

JEL classification: L60, L63, M14

1. Introduction

In 1905, Japan was undergoing a significant historical transition, as the conclusion of the Russo-Japanese War marked the acceleration of industrialization and urbanization alongside the development of the modern nation-state system. During this period, the establishment of small and medium-sized banks proliferated even in regional areas, gradually expanding the financial infrastructure across the country (Okazaki, 2005). Simultaneously, as transportation methods shifted from river shipping to railways, natural geographic conditions such as terrain and waterways played a major role in shaping the economic networks that connected cities and rural regions.

Against this backdrop, the locations of banks serve as important indicators that reflect the realities of regional economic activities and their networks. In particular, local banks established during the Meiji period were often founded by local merchants and entrepreneurs, demonstrating strong ties with the local economy. These banks are thus valuable for understanding the initial conditions

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of economic agglomeration. Accordingly, this study seeks to clarify the spatial distribution of banks in relation to institutional and geographic structures.

Examining the spatial correspondence between bank locations, administrative divisions, and natural geography is essential for interpreting the formation of regional economies during this period. Banks were not merely financial infrastructures; they were central to economic activities closely connected with commerce, logistics, and administration. Their placement thus serves as a key to visualizing the spatial structure and developmental stage of local economies. This study analyzes how natural geographic factors—such as major river basins and the boundaries between mountainous and flatlands—and institutional factors—such as cities and counties—influenced the placement of banks, testing the hypothesis that their locations were shaped by these institutional and geographic structures.

Previous studies have primarily focused on qualitative analyses of modern clusters, such as Silicon Valley (Porter, 1998), or spatial economic theories based on mathematical models (e.g., Krugman, 1991). Few studies have empirically examined the relationship between geographic conditions and industrial agglomeration using historical data. However, Yoshizu (1978) demonstrated that bank locations during the Meiji period were concentrated in commercial centers and strategic points of transportation and administration, suggesting spatial consistency between bank distribution and the regional central place hierarchy. Building on this discussion, the present study reexamines the spatial characteristics of bank locations through quantitative analysis.

Specifically, Voronoi diagrams are generated based on the locations of banks in 1905 and are overlaid with contemporary administrative boundaries and natural geographic features (such as water systems and elevation). The structural consistency between these layers is then quantified using the Multi-Scale Structural Similarity Index (MS-SSIM), a metric for image similarity. This approach enables the study to uncover the spatial order of bank locations based on quantitative evidence, rather than relying on visual impressions alone.

Ultimately, this research aims to clarify the mechanisms of economic formation grounded in institutional and geographic structures from a historical perspective.

2. Study Scope and Period

2.1. Target Region

This study focuses on the Kanto region of Japan as it existed in 1905. The Kanto region encompasses the largest plain in Japan—the Kanto Plain—and is characterized by a complex interplay of plains, hills, and mountainous terrain. Even during the Meiji era, the region had a well-developed network of railways and river transport routes, with Tokyo emerging as the nation's political and economic center.

The analysis covers seven prefectures: Tokyo, Kanagawa, Chiba, Saitama, Ibaraki, Tochigi, and Gunma. These areas include the Tone River, which has the largest watershed in Japan, along with other major Class A rivers, and the massive consumer market of Tokyo. In the Meiji period, these prefectures served as critical hubs of industry and distribution. In northern Kanto—specifically Gunma, Tochigi, and Ibaraki—textile and warehousing industries flourished. Meanwhile, Kanagawa Prefecture conducted outward-facing trade through Yokohama Port, and Tokyo experienced rapid urbanization and the concentration of banking institutions.

2.2. Target Period of Analysis

Under these circumstances, the location of banks was not merely a matter of establishing financial infrastructure, but became a crucial factor in driving regional economic growth. Yoshino & Taghizadeh-Hesary (2018) demonstrated that the density of banks is a decisive factor influencing economic growth, suggesting that clarifying the spatial arrangement of banks is essential for understanding the structural foundations of economic development at the time.

Yoshizu (1978) showed that the establishment of banks during the Meiji era tended to concentrate in commercial centers and strategic nodes of transportation and administration—locations that correspond to upper hierarchical levels in central place theory. In the Kanto region, these "central places" often overlapped with junctions of railway and river transportation networks, indicating that institutional and logistical factors played a significant role in shaping bank locations.

Furthermore, during this period, Japan was transitioning from river to rail transport, and the spatial overlap between transport and financial infrastructure became increasingly evident. In particular, the year 1905 marked a turning point in industrial policy following the end of the Russo-Japanese War. The number of banks nationwide was increasing, and local financial networks led by small institutions were actively forming.

According to Okazaki (2005), even before the financial panic of 1907, regional banks were undergoing mergers aimed at rationalizing management and increasing capital, especially in northern Kanto. Around the same time, a boom in company formation occurred, and local financial institutions played a vital role as providers of startup capital.

Taken together, these observations suggest that bank locations were not merely the result of economic activity, but may have functioned as a "precondition" that shaped the structure of regional economies.

In this study, bank locations in the seven prefectures as of 1905 are identified, and their distribution is analyzed in relation to geographical features (e.g., mountainous and flat areas) and hydrological systems. In addition, the degree of spatial alignment with administrative boundaries is measured to elucidate the relationship between bank distribution and industrial clustering from a spatial perspective.

3. Methodology

3.1. Data Sources

To clarify the spatial distribution of banks in the Kanto region and their relationships with topography and administrative boundaries, this study utilized a range of official documents and geospatial datasets. The location data for banks were extracted from the *Directory of Executives of Companies Nationwide in Japan (1905)*. Bank names and addresses listed therein were converted into latitude and longitude coordinates and geocoded using GIS software.

For topographic data, elevation information provided by the Geospatial Information Authority of Japan was used. Areas were classified into plains and mountainous zones using an elevation threshold of 500 meters. This classification follows criteria adopted by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and previous studies in geography. Regarding river systems, spatial data for Class A rivers were obtained from the National Land Numerical Information database (MLIT) to visualize waterborne transportation routes at the time.

In addition, historical administrative boundaries at the county (郡) level during the Meiji period were reconstructed and digitized within a GIS environment. This allowed the study to capture structural characteristics that would be overlooked by relying solely on modern administrative units.

For the reconstruction of administrative divisions, the "Historical Administrative Boundary Dataset (Beta Version)" was employed. This dataset provides map-based information reflecting the city, town, and village system established in 1889, enabling precise GIS-based recreation of county-level administrative structures of the period.

3.2 Analytical Procedure

The analytical procedure in this study is composed of two stages. First, Voronoi diagrams were generated using bank coordinates as seed points. A Voronoi diagram partitions a space into regions where each region corresponds to the area closest to a given point, making it an appropriate method for visually analyzing the service coverage or spheres of influence of banks. The generated Voronoi regions were overlaid with geographic layers—such as the plains and mountainous classification, hydrological networks, and administrative boundaries—to examine the spatial relationships between bank locations and natural or institutional features. The generation of diagrams followed the method described by Matoschek (2002).

Second, to quantitatively evaluate the spatial similarity between the Voronoi diagrams and administrative boundaries, the Multi-Scale Structural Similarity Index (MS-SSIM) was employed. Originally proposed by Wang et al. (2003), MS-SSIM compares the structural, luminance, and contrast features of images across multiple scales, offering human-perception-aligned assessments of structural consistency.

The appropriateness of MS-SSIM for this study was confirmed from several perspectives. First, map data inevitably involve scaling, rotation, or distortion. MS-SSIM is robust against such transformations. In contrast, traditional metrics such as Intersection over Union (IoU), pixel matching rate, or Dice coefficient are primarily designed for comparing binary images and are less suitable for quantifying structural consistency when dealing with subtle boundary shifts or continuous gradations. Particularly in this study—where complex shapes based on Meiji-era bank locations and administrative boundaries are analyzed—comprehending overall structural integrity is more important than exact pixel-level matches. MS-SSIM excels in this regard due to its multi-level structural evaluation capability.

To demonstrate the superiority of MS-SSIM over conventional similarity metrics, a comparative table is presented below (Table 1).

Table 1: Comparison of Spatial Similarity Metrics – Characteristics of MS-SSIM vs. Traditional Methods

Metric	**Characteristics**	**Advantages**	**Disadvantages**	**Suitability for Spatial Structure Comparison**
MS-SSIM	Multi-scale comparison of structure, luminance, and contrast	Strong for hierarchical structure analysis; robust to scale/rotation	Requires specialized understanding; interpretation is context-dependent	Very High
IoU	Measures area overlap (Intersection over Union)	Simple and intuitive; suited for binary mask comparisons	Sensitive to minor boundary shifts; cannot handle gradations	Rather Low
Dice Coefficient	Symmetric area overlap index similar to IoU	Effective in medical imaging; good for small objects	Weak at capturing geometric differences	Rather Low
PSNR	Pixel-value-based image quality metric	Extremely fast and simple	Ignores structure/luminance; misaligned with visual relevance	Low
Pixel Match Rate	Ratio of matching pixel values	Simplest to compute	Extremely fragile to translation or deformation	Low

As shown in Table 1, each metric has its strengths and weaknesses depending on the nature of the image and the evaluation goal. MS-SSIM stands out in its ability to evaluate structural features across scales. While IoU and Dice coefficients are useful for comparing binary regions, they are limited in addressing subtle structural discrepancies. Simpler metrics like PSNR and pixel match rate are particularly vulnerable to distortions common in map data, such as scaling, rotation, or warping. In contrast, MS-SSIM offers high robustness

and reliability for real-world spatial comparisons, establishing its superiority in terms of accuracy, applicability, and resilience.

Furthermore, MS-SSIM has been increasingly applied in urban growth modeling (Zhang & Du, 2016) and regional spatial comparisons (Hagenauer & Helbich, 2012), confirming its relevance in urban planning and GIS-based research. Incorporating such precedent strengthens both the methodological rigor and empirical foundation of this study.

Practically, the Voronoi and administrative maps were standardized to a resolution of 224×224 pixels and converted into grayscale using OpenCV. This resolution was chosen as a common standard in image recognition and geospatial analysis, balancing structural detail retention and computational efficiency. Bicubic interpolation was used to maintain aspect ratios and minimize structural distortion during conversion. Furthermore, consistency across resolutions was verified by executing MS-SSIM at multiple resolutions, with no significant variation in scores observed.

Pixel values were normalized to the [0,1] range, and the ms_ssim() function from the PyTorch library was used to compute scores for each region. These scores ranged from 0 to 1, with scores above 0.8 interpreted as indicating high structural similarity.

To rule out the possibility that high MS-SSIM scores were due to chance, a Monte Carlo test was conducted. In this procedure, for each prefecture, Voronoi-administrative map pairs were randomly sampled from other prefectures to generate 1,000 synthetic pairs. MS-SSIM scores were then calculated for each pair. The probability of obtaining a score equal to or greater than the observed value was taken as the p-value.

Statistical significance was set at $p < 0.05$. Score generation and random sampling were conducted using consistent parameters within the PyTorch ms_ssim() function. The choice of 1,000 iterations follows precedent in prior studies such as Zhang & Du (2016), ensuring reproducibility and computational efficiency.

Through the introduction of the Monte Carlo test, the study provides quantitative evidence that the structural similarity between bank Voronoi regions and administrative boundaries is not a result of visual impression or random coincidence, but reflects a statistically significant spatial correspondence.

4 Results

4.1 Spatial Consistency between Bank Locations and Administrative Boundaries

4.1.1 Visual Correspondence

A Voronoi diagram was created based on bank locations in the Kanto region as of 1905, and this was overlaid with county-level administrative boundaries of the same period for visual examination of their spatial correspondence (see Figure 1). Additionally, topographic features were considered by classifying the region into mountainous and plain areas using an elevation threshold of 500 meters.

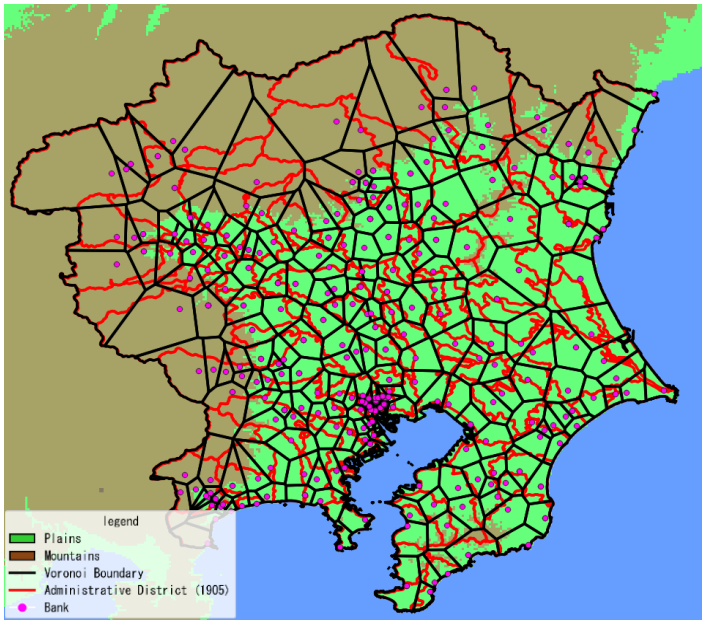


Figure 1: Administrative Boundaries and Voronoi Diagram of the Kanto Region in 1905

As shown in Figure 1, in Gunma, Tochigi, and Kanagawa prefectures, the boundaries of the Voronoi regions closely align with administrative boundaries, indicating a high degree of spatial consistency. While some deviations are observed in Tokyo, the overall alignment remains relatively strong. In contrast, Saitama and Chiba exhibit more noticeable mismatches between the Voronoi diagram and administrative divisions, suggesting relatively low spatial correspondence.

To quantify these visual impressions, the MS-SSIM index was used to evaluate the structural similarity between the Voronoi diagram and county images for each prefecture. Table 2 presents the MS-SSIM scores and the associated p-values obtained through Monte Carlo testing.

4.1.2 Quantitative Evaluation Using MS-SSIM

Table 2: MS-SSIM Scores and p-values for the Spatial Similarity between Administrative Boundaries and Voronoi Diagrams in the Kanto Region

Prefecture	MS-SSIM	p-value
Gunma	0.882	0.010**
Tochigi	0.868	0.032*
Kanagawa	0.865	0.035*
Ibaraki	0.831	0.047*
Tokyo	0.809	0.050*
Chiba	0.788	0.061
Saitama	0.785	0.073

Note: $p < 0.05$ was considered statistically significant.

Gunma, Tochigi, and Kanagawa recorded MS-SSIM scores above 0.86, indicating "high similarity." Ibaraki and Tokyo also exceeded 0.8 and were deemed structurally consistent. In contrast, Chiba and Saitama fell below 0.8, suggesting relatively weaker alignment compared to other prefectures.

To determine whether these scores could be due to random chance, Monte Carlo testing was conducted using MS-SSIM calculations via PyTorch. Specifically, MS-SSIM scores were computed for county and Voronoi image pairs in each prefecture, and 1,000 random pairs from other images in the same directory were generated for comparison. The probability of obtaining a score equal to or higher than the observed value was used as the p-value.

The results indicated statistically significant spatial alignment ($p < 0.05$) in Gunma, Tochigi, Kanagawa, Ibaraki, and Tokyo. This suggests that the structural match between the Voronoi diagram and administrative boundaries in these regions is unlikely to be coincidental. Although Chiba and Saitama showed relatively high scores, they did not reach statistical significance, implying that their structural resemblance is not distinct enough to reject the null hypothesis.

4.1.3 Summary: Structural Alignment between Bank Locations and Administrative Boundaries

Integrating visual observations, quantitative scores, and statistical testing reveals clear regional variation in the spatial alignment between bank locations and administrative boundaries in the Kanto region. In particular, the three northern prefectures—Gunma, Tochigi, and Ibaraki—along with Kanagawa and Tokyo, exhibit a strong structural alignment between bank locations and county boundaries, suggesting that bank distribution tends to conform to Voronoi-based spatial partitioning.

Importantly, these administrative units were not imposed top-down by central authorities but were often shaped by local private organizations and enterprises. This implies that the alignment between counties and bank locations may reflect autonomous decision-making within regional economies. In other words, counties were not merely administrative constructs but were shaped in mutual interaction with local economic functions and human networks. Thus, the observed spatial alignment can be interpreted as the product of dynamic interactions between institutional and economic structures.

Notably, in prefectures such as Gunma, Tochigi, and Kanagawa, it has been reported that network-based entrepreneurs consciously established banks in accordance with administrative boundaries (Suzuki & Kobayakawa, 2010). The spatial consistency confirmed in this analysis empirically demonstrates, through quantitative and statistical methods, the presence of historically rooted spatial structures. Hence, bank locations were not randomly distributed

independent of topography or institutions, but rather formed an orderly spatial pattern shaped by institutional and economic structures.

4.2 Relationship Between Bank Locations, Water Transport, and Topography

4.2.1 Rationale for Focusing on Water Transport Systems

To understand the relationship between bank locations and natural topography during the Meiji period, it is essential to first consider the role of water transport. Although Japan's railway network was expanding rapidly at the time, rivers remained a principal means of transporting goods—particularly heavy and voluminous cargo such as rice, coal, timber, and iron. The Class A rivers in the Kanto region, including the Tone River, spanned broad catchment areas from upstream zones to Tokyo Bay, serving as critical lifelines connecting regional industries to the capital region.

Consequently, logistical hubs emerged at strategic points along these waterways, creating concentrated demand for financial services. It is therefore reasonable to assume that banks tended to be located in areas where river-based logistics were concentrated.

4.2.2 Results: Bank Concentration in Class A River Basins, Centered on the Tone River

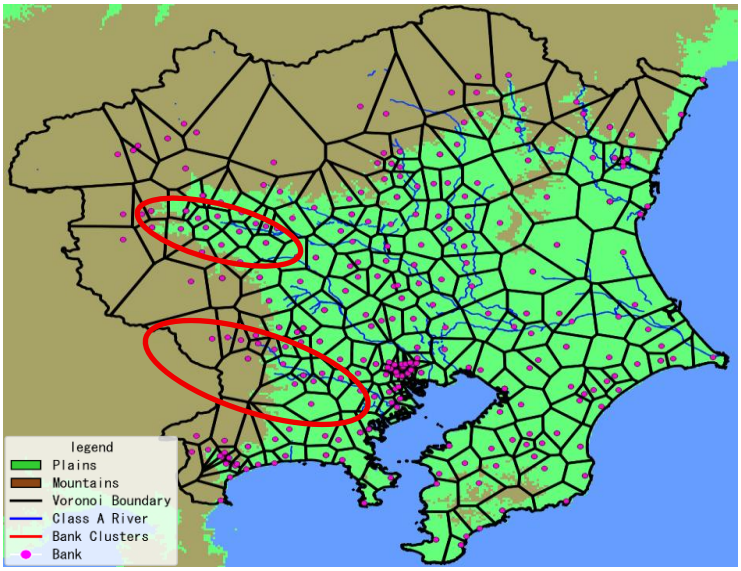


Figure 2: Water Transport Networks and Voronoi Diagram in 1905

As shown in Figure 2, bank locations in the Tone River basin—stretching from Gunma through Saitama to Chiba—are densely concentrated along riverbanks. This suggests that financial institutions were distributed in alignment with the water transport network. Similar trends were observed along other major rivers, including the Arakawa and Tama Rivers. In particular,

the downstream areas flowing into Tokyo Bay served as key logistical endpoints, where large volumes of cargo converged and economic activity intensified. As a result, Tokyo had already become a major banking center by 1905, serving as a vital hub for capital inflows and outflows within the greater metropolitan economy.

4.2.3 Structural Characteristics of River Mouths, Coastal Zones, and Plains

Bank locations were not limited to upstream and midstream zones; notable concentrations were also observed near river mouths. These areas served as intersections between inland and maritime transport. For example, Tokyo Bay's coastal zones—including Yokohama Port and Shinagawa Port—were hubs of commercial activity linked to foreign trade. In Kanagawa Prefecture, banks were densely distributed near these ports, reflecting high demand for financial transactions related to exports and shipping.

In addition, banks were often established in floodplains where river transport intersected with agricultural economies. This pattern was particularly noticeable in eastern parts of Saitama and Chiba. However, since these areas were primarily agricultural—dominated by fields and rice paddies—they had lower population densities compared to urban areas and more limited large-scale financial demand, which may have influenced the degree of bank concentration.

4.2.4 Limitations of Water Transport and Connections to Land Routes

Despite its importance, river transport had limitations. In areas with steep terrain or shallow water, boats could not pass easily, necessitating the transfer of goods to land routes. These intermodal transfer points—where waterborne goods were offloaded for land transport—often developed into warehouse hubs, post towns, and settlements, which were conducive to the establishment of banks.

In fact, in mountainous and hilly areas of Gunma and Tochigi, banks were found at the boundaries between mountain ranges and plains, suggesting their role as intermodal nodes for water and land transport.

4.2.5 Spatial Significance of "Warehouse-Banks"

The functional duality of banks as logistical and financial hubs was embodied in institutions known as "warehouse-banks." Examples include the Hokuetsu Warehouse Bank and the Tochigi Warehouse Bank, which combined financial and storage functions to support both regional distribution and liquidity management.

The location of such institutions along waterways and river basins supports the idea that bank placement was guided by both topographical and economic rationality.

5 Discussion

The results of this study reveal that the spatial distribution of banks in the Kanto region in 1905 exhibited a high degree of alignment with institutional administrative units (i.e., county boundaries) and natural geographic conditions such as rivers and elevation. In particular, in prefectures such as Gunma, Tochigi, and Kanagawa, bank locations closely matched county boundaries, suggesting that institutional regional units also functioned as economic network frameworks. This finding indicates that administrative boundaries were not merely units of governance, but also served as foundations for the formation of economic and spatial networks.

According to Yoshizu (1978), local banks during the Meiji period were often established in locations corresponding to the central-place hierarchy—such as county offices and transportation hubs—and were embedded in commercial centers within each region. This aligns with the results of this study, which confirmed the spatial consistency between Voronoi diagrams and administrative boundaries, indicating that the formation of bank locations followed an orderly pattern rooted in institutional and geographic context.

Furthermore, the concentration of banks along river basins and topographic boundaries suggests that they functioned as spatial nodes that mediated between logistics and finance. This is also consistent with the existence of multifunctional institutions such as “warehouse-banks” at the time. In other words, bank locations were not only determined by existing administrative and logistical structures, but also served as dependent variables that responded to these contexts. At the same time, they acted as mediating variables that influenced the formation and growth of local economic structures by serving as financial service hubs.

Thus, the spatial distribution of banks reflected the institutional and geographic conditions of their time, while also contributing to the reinforcement and stabilization of those very structures. Notably, in prefectures such as Gunma, Tochigi, and Kanagawa, network-oriented entrepreneurs reportedly established banks with a keen awareness of administrative boundaries (Suzuki & Kobayakawa, 2010). This study provides quantitative and statistical confirmation of such spatial coherence, rooted in historical and institutional background.

Therefore, bank locations were not randomly or uniformly distributed. Rather, they formed structured spatial patterns that were aligned with the institutional and economic systems of their time.

6 Conclusion

This study has demonstrated that the spatial distribution of banks in the Kanto region in 1905 showed a notable degree of alignment with natural geographic features—such as topography and river systems—as well as institutional boundaries, particularly administrative units at the county level. By

constructing Voronoi diagrams based on bank locations and comparing them with county boundaries and physical geographic features, the study employed the image similarity metric MS-SSIM to quantitatively evaluate the degree of structural correspondence. The results indicate a high level of spatial consistency between banking service areas and administrative units in Gunma, Tochigi, and Kanagawa, suggesting that the regional financial network was closely linked to institutional divisions.

In contrast, in Tokyo and Saitama, a certain degree of spatial discrepancy was observed. One explanation is that, by 1905, Tokyo had already developed a functional role as the nation's capital, transcending county-level administrative boundaries. As a center of national industrial policy and administrative authority, Tokyo was home to the headquarters of major banks strategically concentrated under state planning. Thus, bank locations in Tokyo were increasingly determined not by administrative boundaries but by policy objectives and central economic functions.

In southern Saitama, the cities of Kawagoe, Omiya, and Urawa were expanding across county lines, forming wider regional markets interconnected by railway networks. This likely enabled a more flexible deployment of bank branches in response to broader economic integration (Inoue, 1995; Sato, 2004).

Furthermore, the fact that many banks were concentrated near key nodes of river transport and topographic boundaries—particularly at the interface between mountainous and flatland zones—demonstrates their role not merely as financial service providers, but as spatial nodes mediating between logistics and economic activity. The existence of "warehouse-banks" in the Tone River basin provides compelling evidence that banks also functioned as distribution hubs. This finding highlights the geographic significance of bank locations as centers of economic activity embedded within the physical landscape.

Although statistical significance was not confirmed in Chiba Prefecture, this may be attributed to the region's relative lack of major Class A rivers, which limited water-based transport and reduced opportunities for economic centralization. Additionally, the peninsula-like shape of the Bōsō region may have restricted inland access, contributing to the fragmentation of economic zones and hindering the spatial expansion and coherence of bank locations.

These findings support Porter's (1998) theory that geographic proximity fosters concentrated networks and competitive advantage, suggesting that such dynamics were already at work during the Meiji era—embedded within both institutional frameworks and natural geography. Similarly, Krugman's (1991) proposition that spatial initial conditions exert lasting influence on the distribution and clustering of industries is empirically validated through the alignment between bank locations, river systems, and topographic boundaries.

Taken together, these results align with the view of Yoshino & Taghizadeh-Hesary (2018), who emphasized the decisive role of banking

density in shaping economic growth. The spatial configuration of financial networks, therefore, was not merely a passive outcome variable, but rather an active agent that shaped the skeletal structure of regional economies. Bank locations were simultaneously a **result** of institutional and geographic conditions and a **precondition** that contributed to the formation and reinforcement of regional economic structures and networks.

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