

Article

Research on the Correlation and Influencing Factors of Digital Technology Innovation in the Guangdong–Hong Kong–Macao Greater Bay Area

Diexin Chen ¹ , Yuxiang Xiao ², Kaicheng Huang ¹ and Xiumin Li ^{1,*}

¹ Department of Economics and Trade, Guangdong University of Technology, 161 St. Yin Long's Street, Guangzhou 510630, China

² Department of Management, Guangdong University of Technology, 161 St. Yin Long's Street, Guangzhou 510630, China

* Correspondence: xiumin.li@gdut.edu.cn; Tel.: +86-153-6057-8850

Abstract: We investigated the digital technology innovation association's spatial distribution characteristics and influencing factors using social network analysis and a negative binomial gravity regression model. The model was based on the transfer of digital technology patent rights among cities in the Guangdong–Hong Kong–Macao Greater Bay Area from 2010 to 2020. The following are the paper's main findings: First, the digital technology innovation association among cities in the Guangdong–Hong Kong–Macao Greater Bay Area is strengthening, and the accessibility and agglomeration of each city node are improving, as are small-world characteristics. Second, for a long time, the four cities of Guangzhou, Shenzhen, Dongguan, and Foshan have been at the epicenter of digital technology innovation. Third, in a more peripheral position, Zhongshan, Huizhou, and Zhaoqing have gradually increased the number of digital technology innovation linkages with other cities. Fourth, technological and institutional proximity positively impact digital technology innovation associations in the Greater Bay Area, whereas geographical distance has a negative impact. The study's findings can be used to help promote digital technology innovation linkages and develop policies for innovation development in the Greater Bay Area.

Keywords: Guangdong–Hong Kong–Macao Greater Bay Area; digital technology; innovation linkage; proximity



Citation: Chen, D.; Xiao, Y.; Huang, K.; Li, X. Research on the Correlation and Influencing Factors of Digital Technology Innovation in the Guangdong–Hong Kong–Macao Greater Bay Area. *Sustainability* **2022**, *14*, 14864. <https://doi.org/10.3390/su142214864>

Academic Editors: Tatiana Čorejová, Radovan Madleňák and Jenny Pange

Received: 16 August 2022

Accepted: 8 November 2022

Published: 10 November 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Regional innovation plays an essential role in the new era of nation-building in the context of the contemporary knowledge economy, and innovation factor resources are gradually becoming strategic [1]. However, as economic and information globalization intensifies, the uncertainty and complexity of innovation grow, and the generation of innovation outcomes increasingly necessitates close collaboration among multiple actors. Cross-regional innovation is gradually emerging as an innovation trend, and regional innovation linkages have emerged as an important research theme [2]. According to some studies, innovation linkages between cities promote the optimization and complementarity of urban innovation functions [3] and the potential benefits of spatial diffusion of innovation [4]. A region's efforts, association, and cooperation with other areas are required to achieve breakthrough development as a technology city [5]. As a result, it is critical to encourage regional interaction and exchange of innovation to boost regional innovation.

The Guangdong–Hong Kong–Macao, Greater Bay Area, is deeply involved in international economic cooperation and science and technology competition as China's international science and technology innovation center [6], and the study of its innovation linkages is a scientific topic with rich connotations. Most academics believe accelerating innovation linkages and cooperation in the Greater Bay Area of Guangdong–Hong Kong–Macao is a

fundamental guarantee for establishing an international science and technology innovation center in the Greater Bay Area [7,8]. Since launching the Guangdong–Hong Kong–Macao Greater Bay Area as a national strategy, the significance of facilitating cross-border factor flow of innovation elements and promoting innovation linkage and cooperation between Guangdong, Hong Kong, and Macao has grown [9]. Some scholars have noted that the Guangdong–Hong Kong–Macao Greater Bay Area’s current innovation-driven development trend is clear, with an overall abundance and concentration of innovation factors and outstanding transformation capabilities. However, there are many barriers to innovation-related cooperation between the three locations, such as institutional differences, uneven resource distribution, different motivation needs, and a situation where the efficient and convenient flow of resources and factors in the Guangdong–Hong Kong–Macao Greater Bay Area has not yet been fully formed [9,10]. In contrast, the Outline of the Development Plan for the Greater Bay Area of Guangdong, Hong Kong, and Macao proposes strengthening the system of innovation and open linkage in various fields in the Greater Bay Area of Guangdong, Hong Kong, and Macao as well as forming an economic strategy and development model in the Greater Bay Area with innovation as the primary support by 2035. As a result, the topic that needs to be studied is how the innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area can rise to the occasion and actively promote innovation linkages and cooperation amidst the opportunities and challenges in the new era of China’s development stage to encourage better the innovative construction and development of the Guangdong–Hong Kong–Macao Greater Bay Area.

The Guangdong–Hong Kong–Macao, Greater Bay Area, is entering a new era led by digital technology, which is flourishing [11]. Information systems scholars regard digital technology as the most recent development in information and communication technology (ICT) as a factor of production [12]. Some researchers argue that promoting the flow of digital technology as an innovation factor and facilitating digital technology linkage and cooperation among cities can improve innovation efficiency and strengthen the Guangdong–Hong Kong–Macao Greater Bay Area’s innovation capacity [11,13]. However, most scholars have focused their research perspectives on innovation production factors such as scientific research knowledge, technological infrastructure, technological innovation talents, and industries in existing studies on innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area [14–22], with reflections on digital technology innovation linkages being rare. According to some scholars, digital technology also suffers from the problem of gathering but not linking and flowing, which will be the most challenging barrier to building a linked innovation system in the Greater Bay Area [23]. Understanding the flow of digital technology as an innovation factor in the Guangdong–Hong Kong–Macao Greater Bay Area, as well as exploring the spatial characteristics of digital technology innovation linkages and their influencing factors, is extremely valuable.

Using Regional Innovation Systems Theory, this paper’s research-specific aims are as follows.

- (1) To analyze and comprehend the spatial distribution characteristics of digital technology innovation linkages in the Greater Bay Area of Guangdong–Hong Kong–Macao.
- (2) To characterize and investigate the spatial pattern and dynamic evolution of digital technology innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area.
- (3) To build and analyze the influencing factors of digital technology innovation linkages in the Greater Bay Area of Guangdong–Hong Kong–Macao.

The contributions of this paper are as follows: first, in the context of the development of digital technology innovation, this paper takes the Guangdong–Hong Kong–Macao Greater Bay Area as the research object, constructs indicators to analyze the characteristics of digital technology innovation association, and analyses its spatial distribution characteristics, which aids in understanding the current situation of the flow of digital tech. Second, by dividing the period, this paper dynamically depicts the evolution of the spatial pattern of digital technology innovation linkages in the Greater Bay Area of Guangdong–Hong

Kong–Macao, which aids in understanding the flow pattern of digital technology as an innovation factor in the Greater Bay Area. Third, by constructing an econometric model, this paper investigates the influencing factors of digital technology innovation linkages from the perspective of multidimensional proximity and innovatively extends the method of measuring institutional proximity. The investigation will help to clarify the mechanism behind digital technology innovation linkages and provides a reference for promoting inter-regional innovation factor interconnection and innovation development in the Guadalcanal region.

The second section of this paper is a review of the literature; the third section introduces the data sources and research methods of digital technology innovation linkages; the fourth section analyzes the characteristics of digital technology innovation linkages and their influencing factors; the fifth section presents the discussion and theoretical contributions; and finally, the research conclusions and corresponding policy implications, as well as the research outlook, are drawn.

2. Theoretical Foundation and Literature Review

2.1. Theoretical Foundation

Regional Innovation Systems Theory

Cooke, a British scholar, first proposed the concept of regional innovation system theory in 1992, stating that a regional innovation system is a regional innovation organization system composed of enterprises, universities, and so on, which are geographically divided and connected; this system supports and generates innovation. The networked system formed by the innovation subjects and their environment in the regional context is the essence of the regional innovation system [24]. Based on this, scholars at home and abroad began to enrich the theory of the regional innovation system, resulting in a slew of theoretical accomplishments. There are numerous definitions of a regional innovation system due to the diverse research perspectives of various scholars. Nonetheless, there are several points of agreement on the primary connotation.

- (1) The regional innovation system is a spatial system with relatively open borders, ranging from large countries to small townships.
- (2) The system's primary innovation agents are universities, businesses, and research institutes as leading R&D agents, and the government, financial institutions, and intermediaries as primary support agents.
- (3) The regional innovation system is a spatial system formed by exchanging and collaborating knowledge and technology via the interaction of various innovation subjects. The system's different elements constantly communicate, influence, and interact with one another.
- (4) Emphasize the significance of regional policies.

Innovation is not limited to a single region. In addition to the activities of internal innovation agents and the exchange of innovation resources, establishing innovation links with organizations outside the area is a critical driver of regional innovation. The flow of innovation factors and the business of innovation activities cross provincial boundaries and play an essential role in advancing the development of innovation systems. This paper investigates the digital technology innovation linkage in the Guangdong–Hong Kong–Macao Greater Bay Area, focusing on each city as an innovation system and exploring the connection between its city systems via digital technology innovation activities.

2.2. Literature Review

2.2.1. Characteristics of Regional Innovation Linkages

The current well-developed transportation network and efficient information-sharing channels effectively promote the spatial transfer of innovation factors such as knowledge, technology, and people, resulting in spatial innovation linkages. Scholars, both at home and abroad, are becoming increasingly interested in the study of urban innovation linkages.

The existing literature focuses on two aspects of research. One method is to estimate and analyze innovation linkages among cities using the entropy TOPSIS, gravity model, or modified gravity model by developing relevant innovation linkage indicators [25,26]. Some scholars, for example, used the gravity model to construct a spatial correlation matrix to analyze the coupled and coordinated spatial linkages in the Guangdong–Hong Kong–Macao Greater Bay Area, concluding that the Greater Bay Area has formed a well-connected ring-shaped innovation network structure [27]. Second, social network analysis and other methods investigate regional innovation linkages' patterns and spatial distribution characteristics [3,22]. For example, some scholars built the Guangdong–Hong Kong–Macao Greater Bay Area innovation linkage network based on the number of invention patent cooperation between cities, ran social network analysis on it, and discovered the innovation linkage among cities in the Guangdong–Hong Kong–Macao Greater Bay Area is growing; its network clustering and grouping abilities tend to improve [28].

Current research on innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area is mainly based on linkage data such as thesis collaboration [14,15,27,29,30], patent collaboration [21,22], patent rights transfer [20,31], or attribute data such as R&D personnel and R&D funding [32]. Because of the limited availability of attribute data, only a smaller number of model variables can be chosen, compromising estimation accuracy. As a result, linked data reveals more regional innovation linkages [28]. Furthermore, some scholars argue that, of the three types of linked data, studies using patent transfer data can provide a more intuitive picture of the flow of technology factor resources while avoiding the influence of factors such as institutional differences and political bias [33,34]. These studies, in general, used complex network theory and social network analysis methods to mine the spatial patterns and characteristics of innovation linkages and discovered that innovation linkages among cities in the Greater Bay Area are established and growing, with features such as small-worldness and spatial aggregation.

2.2.2. Factors Influencing Regional Innovation Linkages

Regarding the influence mechanisms of innovation linkages, the multidimensional proximity theory, which includes geographical, technological, institutional, and social proximity, is widely accepted in academia. Initially, proximity had only one geographical proximity perspective. Nonetheless, many scholars have launched proximity research since then, leading to the continuous enrichment of the concept of proximity and the introduction of a multidimensional proximity concept [35]. The influence of multidimensional proximity on the formation and evolution of thesis cooperation networks, patent cooperation networks, and patent rights transfer networks can be investigated in previous studies by developing econometric models. It also demonstrates that multidimensional proximity has varying degrees of influence on city innovation associations [3,28,29,36,37].

Existing research on the role of multidimensional proximity in influencing innovation linkages varies. First, consider geographical proximity. According to some researchers, geographical proximity facilitates innovation associations [29,36]. According to scholars such as Liberti, innovation is accompanied by the spread of tacit knowledge, which decays with increasing spatial distance and necessitates direct human-to-human communication [38]. Some scholars also argue that the contribution of geographical proximity to innovation linkages is gradually diminishing [28] as information and communication technologies that enable communication over long distances advance. Second, consider technological proximity. Scholars also disagree on the role of technological proximity in their research. This is related to Mowery's "proximity paradox" [39], which states that when technological proximity is low, there is no basis for subject-to-subject innovation linkages due to cognitive level and technical structure differences. As technological proximity grows, so does knowledge complementarity, the need for communication between subjects, and the ability to make innovative connections grows. When technological proximity is too close, the competitive effect between subjects becomes more critical than knowledge complementarity, inhibiting the need to develop innovation linkages [40].

Multidimensional proximity measurement methods are well established. However, in terms of institutional proximity, the existing measures' applicability to the Guangdong–Hong Kong–Macao Greater Bay Area remains to be investigated. Domestic scholars commonly use organizational levels to assess institutional proximity [41–43]. Liu et al. [29], for example. This approach is too simplistic and arbitrary and fails to reflect the Greater Bay Area's unique “one country, two systems” nature. Some academics have analyzed China's provinces and regions using the World Bank's Global Governance Index [44] and the Marketization Index [45]. However, these figures do not include all of the cities in the Greater Bay Area. As a result, this paper investigates a new measurement method that aims to overcome the limitation that Guangdong, Hong Kong, and Macao cannot use the World Bank's Global Governance Index (WGI) and Marketization Index. Eigen [46] and Zhong [47] argue that the magnitude of transaction costs varies across economic systems and that the lower the price per unit of transaction under a specific design, the more efficient that plan is. Based on this concept of transaction efficiency, establishing an index system of transaction cost price index to measure the system's proximity can help scientists understand the impact of institutional differences on the association of digital technology innovation.

3. Data and Methods

3.1. Study Area

After the New York Bay Area, San Francisco Bay Area, and Tokyo Bay Area, the Guangdong–Hong Kong–Macao Greater Bay Area is the fourth-largest bay area in the world. The Greater Bay Area 9 + 2 cities comprise nine cities—Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, and Zhaoqing—and two distinct administrative regions—Hong Kong and Macau. The Greater Bay Area has developed into a crucial innovation growth pole in China over the past 40 years of reform and opening up because of its wealth of innovation energy. The Greater Bay Area's level of R&D investment in 2018 was comparable to that of the UK and Italy. By 2030, it is anticipated that R&D spending in the Greater Bay Area of Guangdong, Hong Kong, and Macau will have increased to a level that rivals that of the San Francisco Bay Area, reaching a level of USD 100 billion, making it the world's top science and innovation bay area in terms of R&D spending on science and technology. The San Francisco Bay Area now ranks as the world's leading science and innovation bay area for R&D spending on science and technology.

3.2. Data

This paper employs extensive data mining and analysis technology to obtain digital technology patent transfer data from the Patent Retrieval and Analysis System of China Knowledge (using the State Intellectual Property Office's Patent Retrieval and Analysis Platform as the data source) for each city in the Guangdong–Hong Kong–Macao Greater Bay Area, from 2010 to 2020, as a proxy variable for the association of digital technology innovation. The following are some specific ideas:

- (1) Patent data mining: the reference object is the Guangdong Province IPR public information comprehensive service platform's patent database of strategic emerging industries. Six primary classification industries and their sub-industries were obtained, namely “new generation communication”, “Internet of Things”, “cloud computing”, “mobile Internet”, “integrated circuit”, and “intelligent equipment manufacturing”. The Patent Search and Analysis System of China Knowledge was then used to obtain a total of 1,452,731 digital technology patent applications in the Great Bay Area and non-Great Bay Area.
- (2) Patent transfer data screening and cleaning: Only data with the legal status “patent transfer” were retained after obtaining all patent application data. Data with incomplete information on patent transfer, no transfer, and international transfer were initially excluded based on the completeness and reliability of the data. The data with unidentifiable addresses of the right holders were excluded before or after the transfer.

We obtained 73,788 digital technology patents' transfer data from the Greater Bay Area and non-Greater Bay Area, including 23,026 Greater Bay Area digital technology patents' transfer data. Finally, manual verification was carried out. We screened and verified the data to eliminate invalid data that the system could not identify automatically.

Key data sources on factors influencing the correlation of digital technology innovation in the relevant Guangdong–Hong Kong–Macao Greater Bay Area: (1) China City Statistical Yearbook, China Statistical Yearbook and Guangdong–Hong Kong–Macao Greater Bay Area City Cluster Yearbook. (2) Guangdong Provincial Statistical Yearbook, Hong Kong Statistical Yearbook, and Macao Statistical Yearbook and Information on the 2015 Guangdong Province 1% Population Sample Survey (upper volume).

3.3. Analytical Approach to the Associated Characteristics of Digital Technology Innovation

The social network analysis method is used in this paper to examine the spatial structure characteristics and evolution trend of the Guangdong–Hong Kong–Macao Greater Bay Area digital technology innovation association. To begin, we created a powerless and directed relationship matrix. According to the direction of the Guangdong–Hong Kong–Macao Greater Bay Area digital technology innovation association, the 11 cities are considered nodes, and digital technology's two-way patent rights' transfer relationships were viewed as edges. The analysis indexes of different dimensions were then visualized and analyzed using UCINET software; precisely four indexes of network density, network connectedness, average path length, and network clustering coefficients at the overall level, and two indexes of degree centrality (including outdegree and indegree) and betweenness centrality at the individual level. Table 1 depicts the relevant evaluation index system.

Table 1. Evaluation index system of digital technology innovation linkage in the Greater Bay Area.

Hierarchy	Measurements	Calculation Formula	Indicator Description
Overall level	Density	$D_e = \frac{2L}{(N-1)}$ (1)	Reflects the closeness of the network
	Connectedness	$C = 1 - \frac{V}{N(N-1)}$ (2)	Reflects the accessibility of the network
	Average path length	$L = \frac{1}{\frac{1}{2}N(N+1)} \sum_{i \geq j}^2 d_{ij}$ (3)	Reflects the efficiency of information transfer in the network
	Clustering coefficient	$C_C = \frac{\sum_{i=1}^N \frac{2E_i}{k_i(k_i-1)}}{N}$ (4)	
Individual level	Degree centrality	$C_D(N_i) = \frac{\sum_{j=1}^N a_{ij}(i \neq j)}{N-1}$ (5)	The most direct indicator of the location of network nodes
	Betweenness centrality	$C_B = \frac{\sum_{j < k} g_{jk}(N_i)}{g_{jk}}$ (6)	

Equation (1) represents the number of nodes; L , the actual number of connected edges; V , the number of unreachable nodes; and d_{ij} , the distance between node i and node j in Equation (3). E_i in Equation (4) represents the number of edges between k_i nodes; k_i , represents the number of points directly connected to node i ; and $a_{ij} = 1$ in Equation (5) indicates that node i and node j have connected edges. $a_{ij} = 0$ indicates that there is no connected edge between nodes i and j . In Equation (6), g_{jk} denotes the number of shortest lines connecting nodes j and k . $g_{jk}(N_i)$ means contains N_i g_{jk} nodes.

3.4. Analytical Approach to the Factors Influencing the Association of Digital Technology Innovation

3.4.1. Indicator

We selected a scientifically sound approach to measure geographic proximity, technological proximity, and institutional proximity based on a multidimensional proximity perspective and previous research and then empirically tested the impact of these factors on digital technology innovation linkages in the Greater Bay Area.

The most straightforward method for measuring geographic proximity is to set the neighboring dummy variable (0, 1), but this does not reflect the degree of geographic proximity between provinces and cities. Geographic proximity can also be measured by spherical distance, but this does not fully reflect the geographic transportation cost of overcoming spatial barriers [42]. As a result, based on the method of Qin and Huang [28], the

shortest highway distance between two cities was used to measure geographic proximity in this paper, which was measured by searching the shortest highway distance between two cities on the official website of China Railway, 12306.

Existing studies have generally accepted and applied Jaffe's [48] concept of technological distance to express the technical similarity between subjects when measuring technological proximity.

$$Tec_{ij,t} = \frac{\sum_{k=1}^n F_{i,tk} F_{j,tk}}{\sqrt{\sum_{k=1}^n F_{i,tk}^2 \sum_{k=1}^n F_{j,tk}^2}} \quad (7)$$

where k represents patents in various technology fields, $k = (1 \dots n)$; and t represents different periods, $t = (1, 2, 3)$. According to the Guangdong IPR public information comprehensive service platform's patent database of strategic emerging industries, this paper divides the digital technology industry into six sub-industries: "new generation communication", "Internet of things", "cloud computing", "mobile Internet", "integrated circuit", and "intelligent equipment manufacturing". In other words, $n = 6$. $F_{i(j),tk}$ denotes the number of patents filed in the k th industry by city i or city j during the t th period. The values of $Tec_{ij,t}$ range from $[0,1]$, and the closer to 1, the higher the technological proximity between city i and city j ; conversely, the closer to 0, the lower the technological proximity between the two cities.

This paper uses Eigen's [46] and Zhong's [47] methodologies to measure institutional proximity. Based on the data available, this paper proposes to establish three main categories of transaction cost price indices, each with five elements for precise measurement: the 2020 inflation rate, the standard deviation of the 11-year average inflation rate from 2010 to 2020, the cell phone subscriber penetration rate, the Internet subscriber penetration rate, and the illiteracy rate of the population aged 15 and above. From 2010 to 2021, the inflation rate in the 11 cities was converted from CPI using 2010 as the base period. The data was then processed: cell phone subscriber penetration rate and Internet subscriber penetration rate were positively correlated with institutional efficiency, and their data were positively standardized; inflation rate in 2020, a standard deviation of the 11-year average inflation rate, and an illiteracy rate of the population over 15 years old were negatively correlated with institutional efficiency, and their data were negatively standardized. The standardized data were built into the direct transaction cost index score, the information and communication index score, and the education index score. The weighted average of the three was used as the index score to calculate each city's transaction cost. The larger the index, the higher the transaction efficiency and lower the transaction cost; the smaller the index, the higher the transaction cost, reducing the transaction efficiency. Finally, by referring to the measure of institutional proximity between regions in Dang and Gong [44], the multiplications of the ratio and mean of the transaction cost indices of two cities in the Greater Bay Area were used to measure the institutional proximity between the two cities.

3.4.2. Model Setting

The measured geographical, technological, and institutional proximity were incorporated into the expanded gravity model to empirically investigate the impact of these factors on the digital technology innovation linkages in the Greater Bay Area of Guangdong–Hong Kong–Macao. Because the patent transfer is count data, which cannot be estimated using ordinary least squares, Poisson regression or negative binomial regression could be used for the study. When the mean and variance of the explanatory variables were calculated, it was discovered that the variance of patent transfer data was much larger than the mean, indicating "overdispersion", and the negative binomial regression model was applicable now [28]. We synthesized the research methods of Duan et al. [49] and Qin and Huang [28] in this paper. The amount of digital technology patent rights transferred between two cities ($TT_{ij,t}$) was used as the explanatory variable, and geographical proximity ($Geo_{ij,t}$), technological proximity ($Tec_{ij,t}$), and institutional proximity ($Ins_{ij,t}$) were also used. The

sum of the two cities' GDP per capita and R&D activity personnel were introduced into the model as control variables. The following are the model expressions:

$$TT_{ij,t} = \alpha + \beta_1 Geo_{ij,t} + \beta_2 Tec_{ij,t} + \beta_3 Ins_{ij,t} + \beta_4 Z_{ij,t} + \varepsilon_{ij,t} \quad (8)$$

where α is the constant term and $\varepsilon_{ij,t}$ is the random error term. $Patent_{ij,t}$ denotes the amount of digital technology patent rights transferred between cities i and j in period t , which also serves as the dependent variable in this study. $Geo_{ij,t}$, $Tec_{ij,t}$, $Ins_{ij,t}$ denote geographical proximity, technological proximity, and institutional proximity, respectively. A set of control variables $Z_{ij,t}$ was also introduced, which is the sum of GDP per capita and R&D activity personnel in the two cities; t denotes the period, and this paper divides the years 2010–2013, 2014–2017, and 2018–2020 in order to examine and dynamically reveal the evolution pattern of digital technology innovation correlation impact mechanism in the Guangdong–Hong Kong–Macao Greater Bay Area.

4. Results

4.1. Characteristics of Digital Technology Innovation Linkages in Guangdong–Hong Kong–Macao Greater Bay Area

To construct a data matrix with weights and directions, we consider each city in the Guangdong–Hong Kong–Macao Greater Bay Area as a node and the digital technology patent rights transfer between cities as an edge. Then, we use UCINET software to calculate network density, network connectedness, average path length, network clustering coefficients, and matrix centralities to reveal the overall and individual characteristics of the digital technology innovation association matrix in the Guangdong–Hong Kong–Macao Greater Bay Area, as well as to depict the spatial pattern of digital technology innovation association in the Guangdong–Hong Kong–Macao Greater Bay Area and its dynamic evolution in time.

4.1.1. General Characteristics of Digital Technology Innovation Linkages in the Greater Bay Area

Table 2 depicts the characteristics of digital technology innovation linkages at the Guangdong–Hong Kong–Macao Greater Bay Area level.

Table 2. General characteristics of digital technology innovation linkages in the Greater Bay Area.

Year	2010–2013	2014–2017	2018–2020
Density	1.736	6.700	6.474
Connectivity	0.818	0.818	1.000
Average path length	1.951	1.500	1.480
Clustering coefficient	8.628	14.915	14.699

The data were calculated by Ucinet software and compiled by the authors.

The Greater Bay Area's network of digital technology innovation linkages is growing. The network density coefficients increased from 1.736 in 2010–2013 to 6.474 in 2018–2020. They indicate that, within the Guangdong–Hong Kong–Macao Greater Bay Area, more cities are experiencing the transfer of digital technology patent rights, and digital technology innovation linkages among cities are becoming more assertive. However, when the coefficients from 2014 to 2017 were compared to those from 2018 to 2020, the differences were insignificant, indicating that the interaction and spillover effects of digital technology innovation elements on each other still have room for improvement and enhancement.

The Greater Bay Area cities' digital technology innovation association has grown significantly. In terms of network correlation change, the coefficient rose from 0.818 to 1. It indicates that as time passes, the accessibility of digital technology innovation factor resources in each Greater Bay Area city in the correlation matrix grew, and they could interconnect directly or indirectly.

The overall accessibility and agglomeration of digital technology innovation linkages among Greater Bay Area cities is gradually improving. In terms of average path length, this coefficient gradually decreased from 1.951 to 1.480, indicating that the dissemination and exchange of digital technology innovation elements among Greater Bay Area cities do not need to rely heavily on the intermediary role of other cities. In contrast, the network clustering coefficient gradually increased from 8.628 to 14.699, indicating that small-world characteristics were more prominent within the Greater Bay Area. It is conducive to optimizing the speed and efficiency of network resource information transmission.

4.1.2. Individual Characteristics of Digital Technology Innovation Linkages in the Greater Bay Area

Table 3 depicts the characteristics of digital technology innovation linkages at the individual level in the Greater Bay Area of Guangdong, Hong Kong, and Macao.

Table 3. Individual characteristics of digital technology innovation linkages in the Greater Bay Area.

Indicator	Time Period	Guangzhou	Shenzhen	Zhuhai	Foshan	Huizhou	Dongguan	Zhongshan	Jiangmen	Zhaoqing	Hong Kong	Macao
Outdegree	2010–2013	19	93	1	4	33	14	4	20	0	3	0
	2014–2017	117	306	20	62	60	129	20	5	10	8	0
	2018–2020	193	229	50	72	21	98	14	12	9	12	1
Indegree	2010–2013	83	28	7	25	2	40	3	1	1	1	0
	2014–2017	140	225	113	43	27	88	63	16	21	1	0
	2018–2020	137	229	32	119	33	70	52	19	17	3	0
Degree centrality	2010–2013	102	121	8	29	35	54	7	21	1	4	0
	2014–2017	257	531	133	105	87	217	83	21	31	9	0
	2018–2020	330	458	82	191	54	168	66	31	26	15	1
Betweenness centrality	2010–2013	20	33	7	2	0	5	3	0	0	8	0
	2014–2017	10	10	1	9	1	3	2	0	9	0	0
	2018–2020	10	16	10	6	0	3	1	2	0	0	0

The data were calculated by Ucinet software and compiled by the authors.

- (1) The growth of digital technology innovation linkages in the Greater Bay Area has been uneven, with the radiation relationship gradually dominating the network.

First, regarding degree centrality, Guangzhou and Shenzhen have long been at the top, with both indicator values significantly higher than other cities. Meanwhile, Dongguan and Foshan are gradually integrating into the core city cluster. From the core cities of Shenzhen and Guangzhou to the central cities of Dongguan and Foshan, the flow of digital technology factor resources demonstrates an apparent preference for geographical proximity. On the contrary, the degree of centralities of cities such as Hong Kong, Macau, and Zhaoqing has consistently been lower than the overall mean. The innovation associated with other cities has failed to accumulate over time.

Second, comparing outdegrees and indegrees reveals that Shenzhen and Hong Kong have maintained that outdegrees are more significant than indegrees, indicating that these two cities are dominated by digital technology innovation flow radiation. In addition to Foshan, Guangzhou, Dongguan, Zhuhai, and other central cities have gradually shifted from having an outdegree that is less than the indegree to having an outdegree that is greater than the indegree. It indicates that these cities have steadily evolved into innovation linkage export cities, gradually increasing their external radiation capacity. Cities on the outskirts, such as Huizhou, Zhongshan, Jiangmen, and Zhaoqing, have an outdegree that is less than the indegree in the third stage, indicating that they are actively developing digital technology innovation links with other cities in the center and gaining more linkage benefits.

- (2) The efficiency of the Greater Bay Area's digital technology innovation linkages is increasing. The overall value of betweenness centrality decreases, indicating that cities in the Guangdong–Hong Kong–Macao Greater Bay Area are gradually developing direct interconnected cooperation and becoming less reliant on other cities

acting as “intermediaries,” which can lower inter-city transaction costs [50]. Five cities—Shenzhen, Guangzhou, Zhuhai, Foshan, and Dongguan—had higher values in all three time periods, indicating that they are essential intermediaries for digital technology innovation linkage cooperation between Hong Kong and Macao and other mainland cities, and had a more significant control role on digital technology innovation linkage among other cities. Because of their low level of digital economy development, relatively backward infrastructure, and poor business environment, Huizhou, Zhaoqing, and Jiangmen have lower betweenness centrality. They are on the outskirts of digital technology innovation linkages. Furthermore, despite being distinct administrative regions, Hong Kong and Macao have fewer connections with other cities due to institutional barriers and other factors. As a result, they have a low centrality in the network of digital technology innovation associations, which limits the regional integration of Guangdong, Hong Kong, and Macao [51].

4.1.3. Evolution of the Spatial Pattern of Digital Technology Innovation Linkages in the Guangdong–Hong Kong–Macao Greater Bay Area

This paper delves deeper into the spatial pattern of digital technology innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area, as depicted in Figure 1. The larger the rectangle of the node, the more central the city is and the more prominent its position in the network. The more frequent and closely connected digital technology patent rights transfer between the two cities, the thicker the line between the nodes. The line connecting the nodes is a directed line segment, and the arrow indicates the direction of digital technology patent rights transfer in each city.

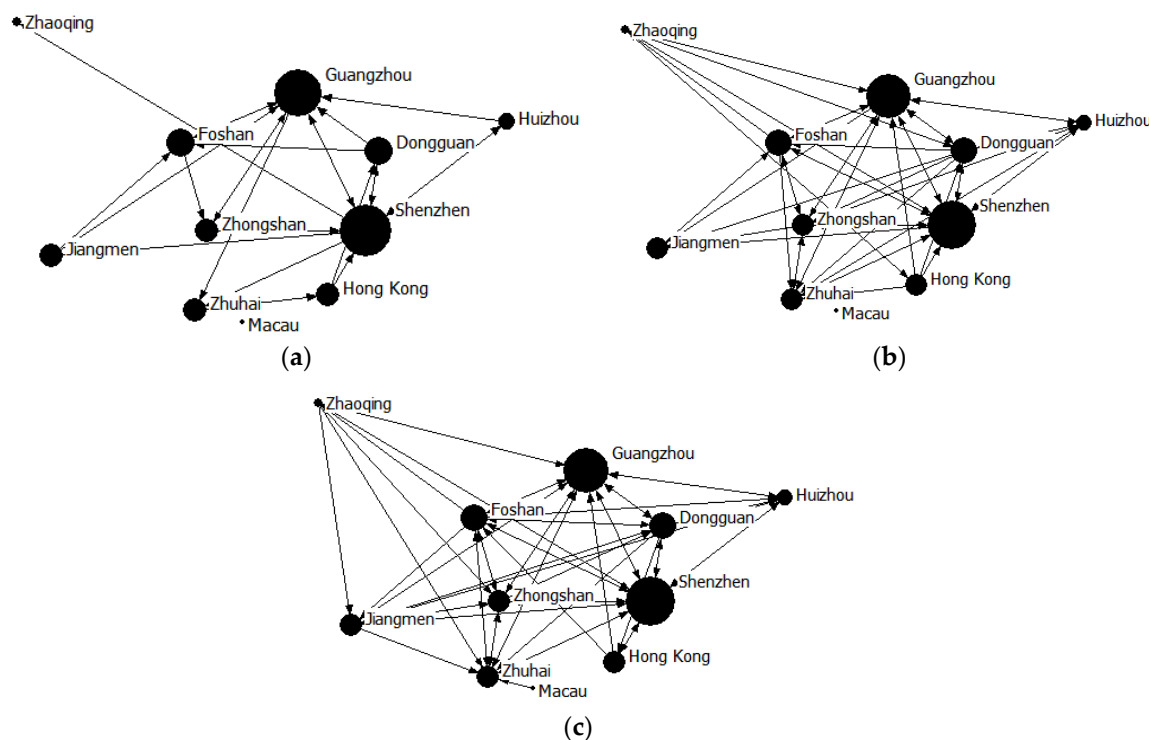


Figure 1. The matrix of digital technology innovation correlation in the Guangdong–Hong Kong–Macao Greater Bay Area: (a) in the 2010–2013 period; (b) in the 2014–2017 period; and (c) in the 2018–2020 period.

The figure shows how the Greater Bay Area’s digital technology innovation linkages have grown closer. Cities in more marginal positions, such as Zhaoqing, Huizhou, and Jiangmen, had few digital technology innovation linkages with other cities between 2010 and 2013. However, after 2013, the number of innovation-related connections between

these cities and other cities increased significantly. It could be linked to China's strategy of innovation-driven development and building a world science and technology power since 2013 [22], which has significantly impacted technology flow and innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area. After 2017, some more marginal cities, such as Zhaoqing and Jiangmen, established innovation linkages successively in the third phase, influenced by a series of national and local policies such as the Framework Agreement on Deepening Cooperation among Guangdong, Hong Kong, and Macao to Promote the Construction of the Greater Bay Area.

Guangzhou, Shenzhen, Dongguan, and Foshan have long been at the center of nodes and lines, and these core cities have maintained close digital technology innovation links. The most important connections are between Guangzhou and Shenzhen. Zhuhai's innovation links with other cities have grown by leaps and bounds, with digital technology innovation links only with Guangzhou, Shenzhen, and Hong Kong in the first phase. Still, the number of connections with other cities has grown significantly in the second phase, and it has achieved links and cooperation with all other cities in the Greater Bay Area in the third phase. This could be because Zhuhai's IT industry has grown enormously and steadily in recent years, with several new-generation IT manufacturing companies. As a result, in the context of innovation development, Zhuhai has created a need to collaborate with other cities for digital technology innovation. Furthermore, Hong Kong and Macau continue to have fewer digital technology innovation links with other cities on the Chinese mainland. They are mostly associated with Guangzhou, Shenzhen, Zhuhai, Foshan, and Dongguan, which are all central cities.

4.2. Analysis of the Influencing Factors of Digital Technology Innovation Linkage in Guangdong–Hong Kong–Macao Greater Bay Area

The analysis can be performed using either a zero-inflated or a regular negative binomial regression models since the explanatory variables have a significant number of zero values or “zero inflation.” In particular, neither the zero-inflated nor conventional negative binomial regression models significantly alter the positivity or negativity of the coefficients of the variables. The Vuong test and the AIC and BIC criteria are used in academia to determine the best models. For non-nested models, Vuong (1989) presented the Vuong non-nested test [52]. The two strictly non-nested models' log-likelihood ratio distributions fulfill normality in this scenario. Wilson discovered through simulation that the standard Poisson regression and the zip model's log-likelihood ratio distributions did not help normalcy, indicating that the Vuong test does not apply to the test for zero inflation [53]. To guarantee the validity and precision of the empirical results, the AIC and BIC tests were added following the Vuong test.

As a result, this paper employs a standard negative binomial regression model for analysis. It incorporates the geographic proximity, technological proximity, and institutional proximity variables into the model (8) to empirically investigate their effects on the association of numerical technology innovation in the Guangdong–Hong Kong–Macao Bay Area. The results show that the Alpha parameters of models 1–7 are not zero, as shown in Table 4. At the 1% level, the original hypothesis of $= 0$ is significantly rejected, indicating that the paper employs standard negative binomial regression for a good fit.

Table 4. Estimation results of the standard negative binomial regression model for the Greater Bay Area.

	Model 1 (2010–2020)	Model 2 (2010–2013)	Model 3 (2014–2017)	Model 4 (2018–2020)	Model 5	Model 6	Model 7
<i>Geoij</i>	−0.025 *** (0.003)	−0.020 *** (0.006)	−0.026 *** (0.003)	−0.027 *** (0.004)	−0.029 *** (0.003)		
<i>Tecij</i>	8.288 *** (2.864)	20.827 ** (9.526)	6.195 * (3.449)	9.549 *** (3.588)		22.312 *** (2.797)	
<i>Insij</i>	1.547 ** (0.650)	−0.214 (1.179)	1.299 (1.082)	3.931 * (2.010)			0.480 (1.478)
<i>GDPp</i>	−0.062 *** (0.012)	−0.052 *** (0.018)	−0.072 *** (0.015)	−0.067 *** (0.013)	−0.068 *** (0.011)	−0.060 *** (0.017)	−0.090 *** (0.020)
<i>RD</i>	0.137 *** (0.014)	0.255 *** (0.052)	0.166 *** (0.022)	0.109 *** (0.010)	0.134 *** (0.016)	0.106 *** (0.016)	0.097 *** (0.018)
_cons	−5.226 * (3.000)	−18.630 ** (9.389)	−2.827 (3.583)	−6.897 * (3.854)	4.062 *** (0.435)	−18.951 *** (2.837)	3.307 *** (1.025)
<i>lnalpha</i>	1.054 *** (0.134)	1.442 *** (0.284)	0.757 *** (0.203)	0.542 *** (0.196)	1.148 *** (0.141)	1.683 *** (0.114)	2.074 *** (0.120)
N	363.000	121.000	121.000	121.000	363.000	363.000	363.000
Wald chi2	387.62	72.45	174.16	242.92	315.03	131.95	39.18
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Log likelihood	−767.568	−163.25519	−285.03313	−292.10848	−778.037	−836.797	−886.340

Values in parentheses are standard errors; ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

First, the regression coefficients in models 1–5 are significantly negative at the 1% level regarding geographical proximity. It suggests that geographical proximity significantly negatively impacts digital technology innovation in the Greater Bay Area of Guangdong, Hong Kong, and Macao. The greater the geographical distance between two cities, the less conducive to the association and cooperation of innovation agents and the generation of digital technology innovation associations, as most scholars believe [54]. In terms of temporal trends, the absolute values of the coefficients show a slight upward trend from 2010 to 2020, indicating that geographical proximity is becoming more important in promoting digital technology innovation associations. The number of short-distance digital technology innovation associations has increased, correlating with the previously mentioned finding that digital technology flows clearly prefer geographical proximity. There are two reasons why geographical proximity can facilitate digital technology innovation linkages between cities. On the one hand, digital technology innovation links involve the exchange and transfer of tacit knowledge, and engaging in face-to-face interactive communication is the most effective way to disseminate it. On the other hand, geographic proximity can reduce the transportation costs of generating technological innovation linkages in digital technologies.

Second, the regression coefficients in models 1–5 are significantly positive in terms of technological proximity. The technological proximity coefficients are more significant in the three time periods from 2010 to 2020, showing a trend of volatility that decreases significantly and then slowly increases. It suggests that technological proximity positively affects digital technology innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area, implying that technological convergence among cities is more conducive to implementing digital technology innovation linkages. Because of the similarities in the structure of digital technology, the two cities are similar in terms of technical specialization and cognitive level, which can ensure effective and smooth communication when innovation linkages occur. However, an overly similar technological structure may increase competition among cities for technological innovation development, leading to negative consequences such as technological “lock-in” [13,26]. It has been discovered that the flow and evolution of technological innovation in the Guangdong–Hong Kong–Macao Greater Bay Area has a noticeable path-locking effect, and the path dependence of its radiation

network is more pronounced, primarily locked in the city pairs of Guangzhou-Shenzhen, Guangzhou-Foshan, and Shenzhen-Dongguan. Side by side, it demonstrates that the Greater Bay Area's technological innovation flow is more inclined to cities with similar technology structures.

Third, in terms of institutional proximity, the total period coefficient in model 1 is significantly positive. It suggests that institutional proximity has a significant positive effect on digital technology innovation linkages and that cities with similar institutional environments can facilitate digital technology innovation linkages. This is due to the similarity in the institutional climates of the two cities, which reduces uncertainty in carrying out innovation linkages, lowers transaction costs, and facilitates the occurrence of digital technology and other elements of innovation linkages. In 2010–2013 and 2014–2017, the impact of the transfer of digital technology patent rights was minimal. However, it had more significant positive effects between 2018 and 2020, indicating that differences in the institutional environment are gradually becoming an issue that must be addressed in the construction of science and technology innovation centers in the Guangdong–Hong Kong–Macao Greater Bay Area. Only by breaking down institutional barriers and increasing two-way policy interaction between the Mainland, Hong Kong, and Macao to the greatest extent possible can we improve the Greater Bay Area's innovation synergy development capacity and guide the proper and orderly flow of digital technology and other factor resources.

5. Discussion and Theoretical Contributions

This paper introduces the digital technology perspective and investigates and analyzes the characteristics of digital technology innovation linkages. In terms of spatial characteristics, the tightness, accessibility, and internal agglomeration of digital technology innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area tend to increase, forming a distinct core-edge structure. However, the digital technology innovation linkages in the Greater Bay Area still have a lot of room for improvement, which is consistent with the findings of previous studies on all innovation elements [3,22,27–29]. Furthermore, we discovered something unique about Zhuhai as a city. Whereas previous studies concentrated on the cities of Guangzhou, Shenzhen, Hong Kong, Macau, or Foshan, this paper discovers: Zhuhai has shown a leapfrog growth in digital technology innovation linkages with other cities in recent years. Zhuhai only had digital technology innovation links with Guangzhou, Shenzhen, and Hong Kong in the first phase (2010–2013), but the number of connections with other cities increased significantly in the second phase (2014–2017), and Zhuhai has achieved links and cooperation with all other cities in the Greater Bay Area in the third phase (2018–2020). Zhuhai's successful experience as a city can serve as a model for other cities' innovation efforts.

This paper investigates the mechanisms by which geographical, technological, and institutional proximity influence digital technology innovation linkages in the Greater Bay Area of Guangdong, Hong Kong, and Macao. Existing studies, however, disagree on the impact of institutional proximity on innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area. Geographic, technological, and economic proximity have positive effects, while institutional proximity has adverse effects, according to studies by Xu and Wu [36] and Liu et al. [29]; geographic proximity has a positive effect on Qin and Huang [28], while technological proximity has a negative effect; studies by Zhong et al. [3] and Wang et al. [37] show that the impact of geographic and other proximity are significantly positive. The effect of geographical proximity is extremely beneficial. The use of the administrative level as a proxy for institutional proximity may be responsible for the negative impact of institutional proximity. Because of the unique nature of the Guangdong–Hong Kong–Macao Greater Bay Area as “one country, two systems,” we use a new research method in this paper rather than simply using administrative level treatment, the transaction cost price index method, discover that institutional structure similarity has a positive effect on the linkage of digital technology innovation between cities. This leads to the conclusion that institutional differences in the Greater Bay Area can stymie digital

technology innovation linkages. This paper extends and applies a research methodology based on a new way of thinking, which can be used to inform future related research.

The novelties of this study are.

- (1) From a research standpoint, innovation. Based on digital technology, this paper offers a new perspective for studying innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area. It has been discovered that the research objects of innovation linkages in the Greater Bay Area of Guangdong–Hong Kong–Macao primarily focus on innovation production factors such as research knowledge, science, and technology infrastructure, science and technology innovation talents, industries, and technologies. There is still a scarcity of research on digital technology as an emerging innovation factor, as well as research on its evolution and mechanism from a network perspective. As a result, this paper examines the characteristics of digital technology innovation linkages and their influencing factors in the Guangdong–Hong Kong–Macao Greater Bay Area from 2010 to 2020 using social network analysis and negative binomial gravity regression models. The features are revealed at two levels: at the overall level, exploring the closeness, association, and accumulation of digital technology innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area; and at the individual level, analyzing the innovation linkages of each city in the Guangdong–Hong Kong–Macao Greater Bay Area, as well as their positions, roles, and functions in the innovation linkage network. This will contribute to the advancement of research on innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area, as well as the development of an international science and technology innovation center in the Guangdong–Hong Kong–Macao Greater Bay Area.
- (2) Methodological innovation in research. This paper overcomes the limitation that the traditional method of measuring institutional proximity does not apply to the Guangdong–Hong Kong–Macao Greater Bay Area and investigates a new measurement method to demonstrate that differences in institutional levels can impede innovation linkages. Multidimensional proximity is a well-established perspective for assessing the impact mechanisms of academic innovation linkages. However, the measurement of institutional proximity has yet to be explored in existing studies on innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area. As a ‘one country, two systems’ region, institutional differences in the Guangdong–Hong Kong–Macao Greater Bay Area cannot be defined solely by administrative levels and are limited by the inability to use global governance and marketization indices. This paper investigates a new research methodology based on this. It develops new proxies for institutional proximity that take into account the Greater Bay Area’s unique characteristics, so that measurement results can more accurately reflect the impact of institutional differences on digital technology innovation linkages and enrich the case of analyzing innovation linkages in the Guangdong, Hong Kong, and Macao Greater Bay Area from a multidimensional proximity perspective.

There are some limitations to this study. To begin, due to factors such as differences in perceptions of intellectual property protection, it was not possible to obtain all of Hong Kong and Macao’s patent data directly through China Knowledge Network’s patent search and analysis platform. Second, when analyzing the influencing factors of digital technology innovation linkages, consider influencing factors such as epidemics, which will be discussed further.

6. Conclusions

6.1. Conclusion

This paper uses the patent database of strategic emerging industries from Guangdong Province’s IPR public information comprehensive service platform as a reference object and China Knowledge Network’s patent retrieval and analysis system as a data source. Using extensive data mining and analysis techniques, we obtained data on the transfer of digital

technology patent rights among cities in the Guangdong–Hong Kong–Macao Greater Bay Area from 2010 to 2020. We began by creating the digital technology patent transfer matrix. Using social network analysis, the characteristics of the digital technology innovation association and the evolution of spatial patterns in the Guangdong–Hong Kong–Macao Greater Bay Area were investigated. The negative binomial gravity regression model was then used to empirically investigate the influencing factors of digital technology innovation association in the Greater Bay Area of Guangdong–Hong Kong–Macao. The following are the key findings.

First, consider the overall characteristics. According to social network analysis, the innovation association of digital technology among cities in the Guangdong–Hong Kong–Macao Greater Bay Area is getting closer and closer between 2010 and 2020. However, the density does not change significantly from the second to third stages, indicating that there is still room for improvement and enhancement. Furthermore, the accessibility and agglomeration of each city node tend to improve, as does the accessibility of digital technology innovation factor resources among each other. The small-world characteristics become more apparent, implying that the internal agglomeration characteristics of the Greater Bay Area’s digital technology innovation association become more prominent over time.

Second, consider individual characteristics. Shenzhen, Guangzhou, Dongguan, Foshan, and Zhuhai are the centers of digital technology innovation associations in the Guangdong–Hong Kong–Macao Greater Bay Area, with most cities gradually increasing their external radiation capacity over time. Furthermore, Zhongshan and Jiangmen, on the outskirts, have steadily increased their ties with other cities in the center. However, because of bottlenecks and constraints in the free flow of innovation factors, Hong Kong and Macao are less connected with other towns in digital technology innovation. Their degree centrality and intermediate centrality are relatively low, causing regional integration in the Greater Bay Area to be constrained.

Third, in terms of spatial pattern changes, Guangzhou, Shenzhen, Dongguan, and Foshan have been in the center between 2010 and 2020. For a long time, these core cities have maintained close digital technology innovation links. Among these, Zhuhai’s innovation connectivity with other cities has increased in the short term. Zhongshan, Huizhou, Zhaoqing, and other more peripheral cities are gradually increasing the number of innovation links with other cities, indicating that these more peripheral cities are actively integrating into the Greater Bay Area’s digital technology innovation linkages. Meanwhile, Hong Kong and Macao remain less connected to technological innovation than other cities.

Fourth, in terms of influencing factors, the negative binomial regression analysis shows that geographical proximity has a significant positive effect on digital technology innovation linkage in the Guangdong–Hong Kong–Macao Greater Bay Area, indicating that the closer the geographical distance between the two cities is, the more conducive it is to generate digital technology innovation linkage; technological proximity has a significant positive effect on digital tech innovation linkage; Institutional proximity has a significant positive impact on the digital technology innovation association in the Guangdong–Hong Kong–Macao Greater Bay Area in general, and it has a more powerful positive effect in the later stages, indicating that the more similar the institutional environment is, the more it can promote the digital technology innovation association.

6.2. Policy Implications

Based on the research results, the following policy implications can be drawn.

To begin, in building an international technology hub in the Guangdong–Hong Kong–Macao Greater Bay Area, digital technology innovation linkages and linked spillover effects among cities should be continuously strengthened to further leverage the central city’s radiation-driven development on neighboring towns. It can be made to Zhuhai’s experience, which has taken the initiative to improve its innovation links with Guangzhou, Shenzhen, Dongguan, and other cities, thereby rapidly improving its digital technology

innovation development level and role in the Greater Bay Area's digital technology innovation linkage.

Second, the Greater Bay Area's geographical and technological proximity will facilitate the linkage of digital technology innovation in Guangdong, Hong Kong, and Macau. We should accelerate infrastructure development, improve connectivity between cities in the Greater Bay Area, reduce transportation time and costs, and create convenient conditions for the flow of digital technology innovation resources; we should promote the popularization and application of digital technology, and strengthen the digital technology innovation linkages of peripheral cities such as Zhaoqing, Zhongshan, and Jiangmen, to name a few. Simultaneously, it is necessary to avoid "technology lock-in," to mobilize the excellent innovation resources of each city in the Greater Bay Area, and to coordinate the cities to determine their positioning and achieve coordinated innovation development.

Finally, the impact of institutional proximity on digital technology innovation linkages in the Guangdong–Hong Kong–Macao Greater Bay Area must be considered. Institutional proximity promotes the efficient flow of digital technology innovation resource elements and the establishment of effective digital technology innovation linkages. As a result, based on the unique characteristics and differences of the Greater Bay Area, we should continue to focus on the common issues of science and technology innovation in the Greater Bay Area and investigate the development of a unified institutional system so that the system can become a guarantee for carrying out innovation-related cooperation and promote the flow of innovation resource elements.

6.3. Future Research

This paper can be used as a reference for future research on the links between digital technology and innovation by other scholars. To better understand the development of digital technology innovation correlation in the Greater Bay Area, we will obtain all Hong Kong and Macao patent data from the relevant international patent information platforms in the following investigation. Furthermore, in our discussion of the influencing factors of digital technology innovation linkage, we consider the influencing factors from a variety of angles in order to fully reflect the mechanism of digital technology innovation linkage.

Author Contributions: Conceptualization, D.C. and X.L.; methodology, D.C. and X.L.; software, D.C. and K.H.; validation, D.C. and Y.X.; formal analysis, D.C.; data curation, Y.X. and K.H.; writing—original draft preparation, D.C.; writing—review and editing, X.L. and K.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China (Grant No. 72173032) and Natural Science Foundation of Guangdong Province (Item No. 2021A1515011958).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We are very grateful to the anonymous referees for their constructive comments and helpful suggestions to improve the quality of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Song, X.; Zhao, Y.H. Study on Regional Innovation Spatial Correlation and Influence Factors in China. *J. Quant. Tech. Econ.* **2018**, *35*, 22–40.
2. Zhou, Z.Z.; Yang, J.; Zhang, Z.A. On the Spatiotemporal Evolution of the Innovation Linkage Network of the Urban Agglomeration in the Yangtze River Delta. *J. Jiangsu Univ. Soc. Sci. Ed.* **2022**, *24*, 85–96.
3. Zhong, Y.; Chen, J. Characteristics and Mechanism of External Innovation Links from the Central Cities of Guangdong–Hong Kong–Macao Greater Bay Area. *Sci. Technol. Manag. Res.* **2021**, *41*, 21–26.
4. Zhang, S.; Sun, Y.W. A Research on the Influence of Technological Innovation Diffusion to Technological Progress—The Exploratory Research based on Grounded Theory. *Technol. Econ. Manag. Res.* **2017**, *27*–31. [[CrossRef](#)]

5. Yang, F.; Du, D.B.; Lin, X. Study on the Spatial Pattern and Spatial Spillover Effects of Chinese Provincial Innovation Outputs. *Soft Sci.* **2016**, *30*, 6–10, 30.
6. Yang, J.L.; Wang, J.E.; Liu, W.D. Characteristics and evolution path of technological innovation in the Guangdong-Hong Kong-Macao Greater Bay Area. *Prog. Geogr.* **2022**, *41*, 1566–1578. [\[CrossRef\]](#)
7. Li, T.C.; Liu, L. Research on the Policy System of Guangdong-Hong Kong-Macao Greater Bay Area Collaborative Innovation. *Sci. Technol. Manag. Res.* **2021**, *41*, 19–27.
8. Zhang, Z.G.; Hu, A.T.; Ye, B.S.; Deng, H.X. Research on the Construction of the International Science and Technology Innovation Center in the Guangdong-Hong Kong-Macao Greater Bay Area. *Urban Insight* **2022**, 18–33, 159–160. [\[CrossRef\]](#)
9. Liu, Y.; Ren, Y.W.; Ma, L.; Wang, Y. Progress, problems, and strategies of innovation and development in the Guangdong-Hong Kong-Macao Greater Bay Area. *Prog. Geogr.* **2022**, *41*, 1555–1565. [\[CrossRef\]](#)
10. Liu, Y.G.; Zhang, J.X.; Wang, F.L. Scalar traps in the coordinated development of the Guangdong-Hong Kong-Macao Greater Bay Area. *Prog. Geogr.* **2022**, *41*, 1677–1687. [\[CrossRef\]](#)
11. Zhang, E.Z.; Xu, K.N.; Cai, Y.Z.; Liu, J.; Wan, X.Q. Digital Economy and High Quality Development in China. *Yuejiang Acad. J.* **2022**, *14*, 80–104.
12. Guo, H.; Yang, Z.E. From Digital Technology to Digital Entrepreneurship: Connotation, Characteristics and Internal Connection. *Foreign Econ. Manag.* **2021**, *43*, 3–23.
13. Tan, H.F.; Xie, L.F. High-Quality Development of Comprehensive National Science Center—Taking Guangdong-Hong Kong-Macao Greater Bay Area as An Example. *China Open J.* **2022**, 77–85. [\[CrossRef\]](#)
14. Ma, H.T.; Huang, X.D.; Li, Y.C. The evolution and mechanisms of megalopolitan knowledge polycentricity of Guangdong-Hong Kong-Macao Greater Bay Area. *Acta Geogr. Sin.* **2018**, *73*, 2297–2314.
15. Gao, S.; Wang, S.J.; Wang, Z.H. Evolution of the Structural Characteristics and Factors Influencing the Knowledge Network of the Guangdong-Hong Kong-Macao Greater Bay Area. *Trop. Geogr.* **2019**, *39*, 678–688.
16. Wang, Y.; Zhang, H.O.; Yue, X.L. Spatial agglomeration and regional development effects of science and technology infrastructures in the Guangdong-Hong Kong-Macao Greater Bay Area. *Prog. Geogr.* **2022**, *41*, 1702–1715. [\[CrossRef\]](#)
17. Sun, D.C.; Liu, Y. Spatial distribution characteristics and influencing factors of scientific and technological innovation talents in the Guangdong-Hong Kong-Macao Great Bay Area. *Prog. Geogr.* **2022**, *41*, 1716–1730. [\[CrossRef\]](#)
18. Wu, F.; Fu, J.Y. A Study on the Coupled and Coordinated Relationship between the Clustering of Scientific and Technological Talents and Regional Economic Development in the Guangdong-Hong Kong-Macao Greater Bay Area. *Innov. Sci. Technol.* **2022**, *22*, 60–69.
19. Ma, L.; Gong, Z.J.; Xu, D. Spatial and temporal changes of the integration of industrial innovation and industrial advantages in the Guangdong-Hong Kong-Macao Greater Bay Area. *Prog. Geogr.* **2022**, *41*, 1579–1591. [\[CrossRef\]](#)
20. Feng, Z.; Cai, H.; Zhou, W. Structural characteristics and spatial patterns of the technology transfer network in the Guangdong-Hong Kong-Macao Greater Bay Area. *Sustainability* **2020**, *12*, 2204. [\[CrossRef\]](#)
21. Balland, P.A.; Boschma, R. Mapping the potentials of regions in Europe to contribute to new knowledge production in Industry 4.0 technologies. *Reg. Stud.* **2021**, *55*, 1652–1666. [\[CrossRef\]](#)
22. Li, W.H.; Li, Q.X.; Qiu, Z.J. Research on Evolution of Cooperative Technological Innovation about Guangdong-Hong Kong-Macao Greater Bay Area Based on Patent Measurement. *Stat. Res.* **2019**, *36*, 74–86.
23. Ye, Y.Y.; Wang, J.S.; Du, K.M.; Yang, W.; He, S.Y.; Liu, Z.Q. Strategic thinking regarding building an international science and technology innovation center in the Guangdong-Hong Kong-Macao Greater Bay Area. *Trop. Geogr.* **2020**, *40*, 27–39.
24. Cooke, P. Regional innovation systems: Competitive regulation in the new Europe. *Geoforum* **1992**, *23*, 365–382. [\[CrossRef\]](#)
25. Niu, X.; Chen, X.D. Innovation Connection between Cities and Spatial Structure of Innovation Network. *Chin. J. Manag.* **2013**, *10*, 575–582.
26. Jiang, T.Y.; Hua, M.H. Research on Regional Innovation Spatial Linkage of Yangtze River Delta. *Forum Sci. Technol. China* **2014**, 126–131. [\[CrossRef\]](#)
27. Wang, F.F.; Yang, Z.C.; Li, X.T.; Li, X.Y. Research on the Spatial Structure and Connection of Regional Innovation System Coupling Coordination in the Guangdong-Hong Kong-Macao Greater Bay Area. *Sci. Technol. Prog. Policy* **2021**, *38*, 34–43. [\[CrossRef\]](#)
28. Qin, C.L.; Huang, L.J. An Analysis of the Urban Synergy Innovation Relationship and Its Constraints on Guangdong-Hong Kong-Macao Greater Bay Area. *J. Beijing Univ. Technol. Soc. Sci. Ed.* **2020**, *20*, 56–65.
29. Liu, J.; Cai, P.X.; Wang, F.F. Study on the Evolution of Knowledge Innovation Cooperation Network Structure and Influencing Factors in Guangdong-Hong Kong-Macao Greater Bay Area City Cluster. *Techno-Econ.* **2020**, *39*, 68–78.
30. Huang, W.H.; Yao, Z.H. Current Situation and Spatial Structure of Scientific Research Cooperation and Innovation Among Universities in Guangdong-Hong Kong-Macao Greater Bay Area: Analysis of Social Networks Based on the National Knowledge Infrastructure Database. *Sci. Technol. Manag. Res.* **2022**, *42*, 87–93.
31. Li, W.H.; Zhang, Z.X. Research on the Evolution of Hong Kong's Cross Border Technology Innovation Transfer Network: Based on patent measurement information. *Sci. Technol. Ind.* **2022**, *22*, 334–342.
32. Zhou, Z.J.; Su, R.B.; Duan, Y.H.; Shi, Y.S. Research on the Current Situation and Influencing Factors of the Flow of Scientific and Technological Talents in Guangdong-Hong Kong-Macao Greater Bay Area. *Urban Insight* **2020**, 7–19. [\[CrossRef\]](#)
33. Hagedoorn, J.; Cloudt, M. Measuring innovative performance: Is there an advantage in using multiple indicators? *Res. Policy* **2003**, *32*, 1365–1379. [\[CrossRef\]](#)

34. Liu, C.; Niu, C.; Han, J. Spatial dynamics of intercity technology transfer networks in China's three urban agglomerations: A patent transaction perspective. *Sustainability* **2019**, *11*, 1647. [[CrossRef](#)]
35. Li, L.; Luo, D.Z. Multi-proximity and Innovation: The Retrospect and Prospect on Western Researches. *Econ. Geogr.* **2013**, *33*, 1–7+41.
36. Xu, P.Y.; Wu, G.H. Spatial evolution of the knowledge innovation network in Guangdong-Hong Kong-Macao Greater Bay Area—The role of Shenzhen technological innovation hub. *China Soft Sci.* **2019**, *5*, 68–79.
37. Wang, F.F.; Yang, Z.C.; Wu, Y.X.; Chen, A.C. Spatial Structure and Influencing Factors of Innovation Cooperation Network in the Guangdong-Hong Kong-Macao Greater Bay Area. *Urban Insight* **2021**, *89–100*, 117. [[CrossRef](#)]
38. Liberti, J.M.; Petersen, M.A. Information: Hard and soft. *Rev. Corp. Financ. Stud.* **2019**, *8*, 1–41. [[CrossRef](#)]
39. Mowery, D.C.; Oxley, J.E.; Silverman, B.S. Technological overlap and interfirm cooperation: Implications for the resource-based view of the firm. *Res. Policy* **1998**, *27*, 507–523. [[CrossRef](#)]
40. Xia, L.J.; Xie, F.J.; Fu, B.H. The Network Evolution of China Cross Region Industry-University Collaborative Innovation and the Analysis of Influencing Factors: Based on the Perspective of Proximity. *Chin. J. Manag.* **2017**, *14*, 1795–1803.
41. Zhou, M.; Sun, L.Y. The transfer of patent right, characteristics of spatial network and the way for regional collaborative innovation in the area of Beijing, Tianjin and Hebe. *Stud. Sci. Sci.* **2016**, *34*, 1736–1743, 1760.
42. Zhou, R.B.; Qiu, Y.F.; Hu, Y.Z. Characteristics, Evolution and Mechanism of Inter-city Innovation Network in China: From a Perspective of Multi-dimensional Proximity. *Econ. Geogr.* **2021**, *41*, 1–10.
43. Cui, X.S. Empirical Study on the Effect of Business Environment on Economic Development along the “Belt and Road” Initiative Area: Based on the Analysis of World Bank Business Environment Indicator System. *J. Beijing Technol. Bus. Univ. Soc. Sci.* **2020**, *35*, 37–48.
44. Dang, X.H.; Gong, Z.G. Impact of Multidimensional Proximities on Cross Region Technology Innovation Cooperation—Experical Analysis Based on Chinese Coinvent Patent Data. *Stud. Sci. Sci.* **2013**, *10*, 1590.
45. Tao, C.Q.; Peng, Y.Z. Spatial spillover effect of knowledge potential energy on regional technological innovation efficiency under the institutional proximity. *Contemp. Financ. Econ.* **2018**, *2*, 170.
46. Eigen-Zucchi, C. The Measurement of Transactions Costs. Master's Thesis, George Mason University, Fairfax, VA, USA, 2001.
47. Zhong, F.G. The Impact of Transaction Costs on Economic Performance. A Comparison of Three Locations on Both Sides. Ph.D. Thesis, Sun Yat-sen University, Kaohsiung, Taiwan, 2003.
48. Jaffe, A.B. Technological opportunity and spillovers of R&D: Evidence from firms' patents, profits and market value. *Am. Econ. Rev.* **1986**, *76*, 984–1001.
49. Duan, D.Z.; Du, D.B.; Chen, Y.; Huo, Q.H. Spatial-temporal Complexity and growth mechanism of city innovation network in China. *Sci. Geogr. Sin.* **2018**, *38*, 1759–1768.
50. Tang, C.H.; Zhang, X.C. The Structure Evolution of Cooperation Network on Global City Region: A Case Study of Guangdong-Hong Kong-Macao Greater Bay Area. *Econ. Geogr.* **2022**, *42*, 25–34.
51. Liu, J. Ecological Restructuring of Industrial Innovation in the Guangdong-Hong Kong-Macao Greater Bay Area: A New Theoretical Framework. *Henan Soc. Sci.* **2022**, *30*, 99–111.
52. Vuong, Q.H. Likelihood Ratio Tests for Model Selection and Non-Nested Hypotheses. *Econometrica* **1989**, *57*, 307–333. [[CrossRef](#)]
53. Wilson, P. The misuse of the Vuong test for non-nested models to test for zero-inflation. *Econ. Lett.* **2015**, *127*, 51–53. [[CrossRef](#)]
54. Xian, G.; Zeng, G.; Cao, X.Z. Structural feature and proximity mechanism of Chinese intercity innovation network. *World Reg. Stud.* **2018**, *27*, 136–146.